THE STUDY OF RADIO FREQUENCY INTERFERENCE (RFI) FOR RADIO ASTRONOMY IN SOME REMOTE LOCATIONS IN PENINSULAR MALAYSIA

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Abstract

Radio Frequency Interference (RFI) is the main parameter to find the best site for radio astronomy research development. The increasing levels of RFI will pose a big problem for researchers in the radio astronomy field. The radio astronomers are encouraged to choose sites as free as possible from interference. In this research we aimed to survey the RFI at frequency 1 MHz-2000MHz to look the overview of the RFI profile and at frequency 1419 MHz-1421 MHz to monitor the RFI profile at Hydrogen line frequency (1420.4 MHz). We chose Peninsular Malaysia as the research area for RFI observation. We have used the Geographical Information System (GIS) software to find and create the lowest RFI mapping area in Peninsular Malaysia. Proper decision-making processes for selection of lowest RFI sites requires collection of information about various parameters like the density of Malaysian citizen’s data, communication transmitter station’s area data, road network, and land contour data. After recognizing a few suitable areas we will commence to the sites and construct the RFI observations. An RFI survey at that selection site will be done using an omni-directional discone antenna in wideband and narrowband methods. This method provides a basic way of determining the strength of the RFI at observation sites. Eventually, the best area base will be decided from the observations. The results of this experiment will support the development of the first radio telescope in Malaysia and provide the suitable area for radio astronomical observations in Peninsular Malaysia. From the GIS analysis, we have found three potential sites. They are Sekayu (Latitude: 04^{o}57.967’ N, Longitude: 102^{o}57.332’ E), Bertam (Latitude: 05^{o}09.991’ N, Longitude: 102^{o}02.764’ E) and Jelebu (Latitude: 03^{o} 03.108’ N, Longitude: 102° 03.912’ E). The RFI results showed that Sekayu

is the best site for future radio astronomical observation in Peninsular Malaysia with average signals in wideband as -152.32 dBWm^{-2}Hz^{-1} which is equivalent to 5.86 x 10^{-16} Jy and in narrowband as -153.93 dBWm^{-2}Hz^{-1} which is equivalent to 4.04 x 10^{-16} Jy.

Abstrak

Gangguan frekuensi radio (RFI) adalah parameter utama dalam mencari kawasan yang terbaik untuk pembangunan bidang Astronomi radio. Peningkatan aras gangguan frekuesi radio akan memberikan masalah besar kepada penyelidik dalam bidang Astronomi radio. Penyelidik Astronomi radio digalakkan untuk memilih kawasan yang bebas daripada gangguan frekuensi radio. Penyelidikan ini bertujuan untuk memantau gangguan frekuensi radio pada frekuensi 1MHz-2000 MHz. Ini adalah untuk melihat secara keseluruhan profil gangguan frekuensi radio. Selain itu penyelidikan ini juga bertujuan untuk memantau gangguan frekuensi radio pada frekuensi 1419MHz-1421MHz. Ini adalah untuk mengawasi profil gangguan frekuensi radio pada frekuesi garisan Hidrogen (1420.4 MHz). Saya memilih Semenanjung Malaysia untuk pemantauan gangguan frekuensi radio. Saya telah menggunakan perisian 'Sistem Maklumat Geografi' (GIS) untuk mencari dan memetakan kawasan gangguan frekuensi radio paling rendah di Semenanjung Malaysia. Proses membuat keputusan yang bagus diperlukan untuk memilih parameter kawasan yang rendah gangguan frekuensi radio seperti data kepadatan penduduk, data kedudukan pemancar telekomunikasi, data jaringan jalan dan data keadaan tanah .Selepas mengenal pasti beberapa kawasan yang sesuai saya akan ke tempat tersebut dan memulakan pemantauan gangguan frekuensi radio. Pemantauan gangguan frekuesi radio akan menggunakan antenna satu hala, diskon untuk kaedah pemantauan 'jalur luas' dan jalur sempit'. Kaedah ini akan menyediakan langkah yang mudah untuk menentukan kekuatan gangguan frekuensi radio di tempat pemantauan. . Akhirnya kawasan yang paling bagus akan dipilih berdasarkan

keputusan pemantauan tersebut. Keputusan daripada penyelidikan ini akan menyokong kepada pembangunan teleskop radio yang pertama di Malaysia dalam usaha untuk menyediakan kawasan yang sesuai untuk pemantauan astronomy radio di Semenanjung Malaysia. Daripada keputusan analisa GIS, saya telah menjumpai tiga kawasan yang berpotensi. Ia adalah Sekayu (Latitud: 04^{o}57.967' N, Longitud : 102^{o}57.332' E), Bertam (Latitud: 05^{o}09.991' N, Longitud: 102^{o}02.764' E) and Jelebu (Latitud: 03^{o} 03.108' N, Longitud:102° 03.912' E).Keputusan gangguan frekuensi radio menunjukkan Sekayu adalah kawasan yang terbaik untuk pemantauan astronomi radio pada masa hadapan di Semenanjung Malaysia dengan purata isyarat dalam jalur luas adalah -152.32 $dBWm^{-2}Hz^{-1}$ yang bersamaan dengan 5.86×10^{-16} Jy dan jalur sempit adalah -153.93 yang bersamaan dengan 4.04×10^{-16} Jy.

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Contents

List of Figures

List of Tables

Symbol	Definition
λ_{meters}	— Free-space wavelength in meters
D	— Directivity of the antenna
U	— Radiation intensity of the antenna
U_i	— Radiation intensity of an isotropic source
P	— Total power radiated
D_{max}	— Maximum directivity
U_{max}	— maximum radiation intensity
$\mathbf{G}_{dBi}$	— Gain
A	— Area (in $metre^2$)
η	— Efficiency of the antenna
E^t	— Total antenna efficiency
E^a	— Reflection (mismatch) efficiency
E^b	— Conduction efficiency
E^c	— Dielectric efficiency
$\vec{E}$	— Electric field component,
$\vec{H}$	— Magnetic field component,
N	— Noise power
k	— Boltzman’s constant
T	— Temperature in Kelvin
B	— Bandwidth of the system in Hz

RBW	— Resolution bandwidths
NF	— Noise figure
P and ΔP	— Power spectral density of the noise
Δf_0	— Change in frequency
t	— Integration time (assumed as 2000s)
T_A	— Antenna noise temperature
T_R	— Receiver noise temperature
c	— Speed of the light
ΔP_H	— Interference power
S_H	— Spectral flux density

Chapter 1

Introduction

1.1 Background

Radio Astronomy is a young research field in Malaysia even though it has been started since 1934 in the world of science. Most people do not know what this field is all about including its significance. However, since the launching of the National Astronaut Program handled by the Malaysian National Space Agency, the government has now started to give due consideration and beginning to look into astronomy in more seriously. Even still, many Malaysians can not differentiate between the conventional and more popular optical astronomy (which is called simply 'astronomy') and radio astronomy. Both types of radiation from the sky can be observed from the ground level, unlike other wavelengths of radiation such as infra-red and ultra-violet, which cannot penetrate the Earth's atmosphere.

Radio astronomy is part of astronomy. It deals with the origins and nature of emissions from extraterrestrial sources in the radio wavelength range of electromagnetic radiation rather than in the visible range. Radio astronomy can be defined as a field of research involving observations of celestial objects emitting radio waves. In this sense, radio astronomy is different from optical astronomy, which observes celestial objects emitting light radiation.

Generally light radiation is produced by thermal objects while radio signals are produced by thermal and non-thermal objects. Radio astronomy can be done at daytime or rainy days, unlike optical astronomy, which is very much dependent on cloudless nights. Radio signals can travel further than light radiation. Examples of these types of objects are pulsars and quasars.

The most significant research of radio astronomy is the discoveries of Cosmic Microwave Background, Dark Matter and Black Holes. These discoveries form the basis of fundamental theories in cosmology, especially the Big Bang theory. More than 60% of our knowledge of the current theories in astrophysics and cosmology are actually results from discoveries in radio astronomy researches.

Basically, in radio astronomy observation, radio waves emitted by celestial objects will be received by an antenna, called the radio telescope. Another common design, a parabolic dish antenna replaces the mirror plays the role of the reflecting optical telescope in optical astronomy. This dish antenna is used to focus the radio waves from celestial objects into a concentrated signal that is filtered, amplified, and eventually analyzed using a spectrum analyzer. The radio signals received from space are extremely weak, and long observing times are required in order to collect a useful amount of signals. That is why most radio telescopes are mounted to automatically track a given object as its position changes due to the rotation of the earth [1][2][3].

To start any radio astronomical observation, it is important to identify all the possible radio frequency interferences (RFI) in the targeted observational windows. This is because RFI will disturb signals from celestial objects which pose a large problem for radio astronomy observations.

The sources of the RFI are monitored by Malaysian Communications and Multimedia Commission (MCMC) while radio astronomical sources are listed by International Astronomical Union (IAU) [4]. We will carefully identify all RFI in between the chosen RF window of 1-2060 MHz. Within this range, there are eight radios astronomical windows, but we are interested in the Hydrogen line window at a frequency of 1420.4 MHz. We measured the levels of RFI within these windows and deduce if there are any possible radio astronomical observations that can be done in any of the windows at the location chosen.

In this research, we will use the Geography Information System (GIS) software in order to find potential sites in Peninsular Malaysia based on the information of the radio environment of different potential sites, such as population density, transmitter location, road networks, population and land contour data. The details about the parameters will be discussed in Chapter 3. Obviously, the interpretations of the spectrum monitoring measurements are not free from uncertainties. After several sites are selected, the RFI survey will be done and the results will be analyzed to choose the best and most suitable site for Radio Astronomy observation in Peninsular Malaysia.

1.2 Objectives of Dissertation

The main objective of this dissertation is to study the sources and the strength of RFI levels at various locations in the Peninsular Malaysia at Hydrogen line frequency (1420.4 MHz). Our research is guided by the following key performance areas or specific objectives:

1. Perform the GIS software analysis for radio astronomical selection site in Peninsular Malaysia. This process includes traveling to potential sites and collecting the RFI data level and eventually choosing the best site for radio astronomical observations in Peninsular Malaysia.
2. Perform RFI observations at a frequency of 1 MHz until 2000 MHz in wideband setup at the chosen site. The purpose of this process is to monitor the entire signal in that band and the strong signal that could disturb the radio astronomy signal.
3. Perform a 24 hour RFI observation at the frequency range of 1419 MHz-1421 MHz in the narrowband setup at the chosen site. The purpose of this process is to monitor the RFI level that could appear in the Hydrogen line frequency and to investigate the signal fluctuations at the chosen site.

1.3 Structure of Dissertation.

In order to avoid confusion and to facilitate proper understanding of the proposed research topic, an attempt is made to present the material under scrutiny, in a concise, comprehensible and structured manner. First and fore-most, familiarity with the title of the research topic and the problem statement is of utmost importance. These have already been discussed in the title page and in the introduction respectively.

Chapter 2 introduces the literature review with an introduction and concepts of GIS which to be implemented in this research, is discussing in this chapter. This chapter also discusses RFI more deeply such as the definition, types and sources, classes, and characteristics. Furthermore, this section will also discuss the various subsystems of the RFI measuring system that have been used in this research such as antennas, spectrum analyzers and amplifiers. The theory behind this system is studied in detail.

Chapter 3 discusses the implementation of GIS software in radio astronomical observation selection sites. It covers the methodology that has been used in this research using the software. The functions in the software will be discussed in more detail in this chapter.

In Chapter 4, a basic block diagram of the radio frequency interference measuring system that was built is outlined. This is followed by a review, assessment and analysis of field measurements as obtained from the RFI protocol. The method and the RFI measurements are presented. This chapter ends with the description of the RFI data processing.

Chapter 5 is an in-depth analysis of a sample of the RFI raw field data obtained during the RFI observation. The spectral flux densities versus frequency graph from the

RFI data observation are presented from the entire selection potential site. It covers the wideband and narrowband analysis. Comparative studies between the selected potential sites are performed in order to select the best and most suitable site for radio astronomical observation in Peninsular Malaysia. The results from the GIS analysis are also outlined such as the parameter maps and the potential of the RFI observation site in Peninsular Malaysia.

We conclude in Chapter 6, by summarizing our work, discussing future endeavors and making recommendations.

Chapter 2

Background and Literature Review

2.1 Frequency Spectrum Management

Frequency spectrum management is very important to every country. It covers a variety of aspects such as communication, telecommunication, broadcasting, and even military usages. In Malaysia, the allocation of the frequency spectrum is managed by MCMC. This organization will manage all frequency usages by the public. The table of allocation spectrums is depicted in Chapter 1. Table 1.2 is the summary of the radio astronomy frequency observations that exists in Malaysia between frequencies 1 MHz – 2060 MHz. A complete table of frequency allocations can be found in the MCMC manual of spectrum plan, Resources Assignment Management Department 2006.

2.2 Radio Frequency Allocation in Malaysia

The table below is a summary of the spectrum allocation in Malaysia in comparison to International Telecommunication Union (ITU) for the band of 1 MHz to 2060 MHz. Table 2.1 shows eight radio astronomical windows that already exist in radio astronomy. It also confirms the fact that the Malaysian allocation is not totally the same with ITU [4][5]. The

Hydrogen line frequency reserved for Radio astronomy activities can be seen in Appendix B.

Table 2.1: Radio spectrum allocation in Malaysia and ITU.

No	Frequency (MHz)	Malaysian allocation	ITU allocation	Application in radio astronomy
1	13.36 - 13.41	Fixed, Radio Astronomy	Fixed , Radio Astronomy	Solar observation
2	25.55 - 25.67	Exclusively for Radio Astronomy	Exclusively for Radio Astronomy	Jupiter observation
3	37.50 - 38.25	Fixed, mobile, Radio Astronomy.	Fixed, mobile, Radio Astronomy.	Continuum observation
4	73.00 - 74.60	Exclusive use for Government of Malaysia	Radio Astronomy	Solar wind observation
5	150.05 - 153.00	Fixed, mobile	Fixed, mobile, Radio Astronomy	Pulsar observations. Solar observations.
6	322.00 - 328.65	Fixed, Mobile, Government Malaysia, Radio Astronomy	Fixed, Mobile, Radio Astronomy	Deuterium observation
7	406.00 - 410.00	Fixed, mobile, Radio Astronomy.	Fixed, mobile, Radio Astronomy.	Pulsar observation
8	1400.00 - 1427.00	Earth exploration-satellite (passive), Space research (passive), Radio Astronomy	Earth exploration-satellite (passive), Space research (passive), Radio Astronomy	Hydrogen line observation

2.3 Problems of Radio Frequency Interference on Radio Telescopes

Delopments in communication and telecommunication fields are the major contributors of man-made RFI in Malaysia and pose a threat to the future of Radio Astronomy. In bands below 2 GHz, interferences mainly come from broadcasting services, communication data, satellite communication, aeronautical satellites, meteorological satellite and radio navigation satellite. Although some bands are specifically reserved for radio astronomy as mentioned in Table 1.2, we still do not know the protection level of the bands. Stop band filters of some communication systems and others RFI sources are not always adequate [6].

The sensitivity of a radio telescope was lower in the 1940s. The sensitivity of the radio telescope has been increased 100 times now after the Square Kilometer Array (SKA) was constructed. The radio radiation from man made activities increased more quickly with rapid development of radio antenna’s sensitivity. Meanwhile radio telescopes are susceptible to nearby bands because the received signals of interest are extremely weak. Interference may enter a telescope through its antennas and through the analog subsystems, such as the front end and intermediate frequency (IF) subsystems. Because of the high gain of radio-telescope antennas and the fact that celestial signals are generally a quantity in comparison, the primary path for interference is through the antennas [6][7].

RFI will enter the antenna through its primary beam. Although primary-beam widths typically vary from seconds of arc to a few degrees, it is unlikely that the primary beam will be pointing to an RFI source. Because of the extreme sensitivity of a telescope, the relatively high power of RFI damage to the telescope may occur if RFI enters through the primary beam [6]. Table 2.2 shows the RFI sources that exist in Malaysia. These sources have the potential to disturb the radio astronomical observation in Malaysia.

Table 2.2: RFI sources in Malaysia from 1 MHz -2060 MHz [4][5].

No	Main Signal Sources	Frequency (MHz)
1	Radio Broadcasting- Traxx FM	80.0 – 108.0
2	Aeronautical Mobile	125.0 – 150.0
3	Broadcasting Mobile (Tv-Channel 5)	175.0 – 217.5
4	Deuterium (DI), Fixed and Mobile	327.5
5	Mobile Satellite (intermittent)	150.0
6	Meteorological Satellite	462.5
7	Broadcasting (Tv-channel 33)	552.5 – 582.5
8	Broadcasting (Tv-channel 38)	574.0 - 700
9	Broadcasting-(Tv-channel 48)	700.0 – 800.0
10	Mobile Phone(Celcom, Maxis, Digi)	890 - 933.0
11	Aeronautical Radionavigation	1000.0 – 1200.0
12	Radio Location and Radionavigation Satellite	1215.0 – 1240.0
13	Mobile Satellite	1515.0 – 1527.0
14	Mobile Satellite	1622.5 -1692.5
15	Mobile Phone (GSM) (Celcom, Maxis, Digi)	1735 – 1880
16	Telekom Malaysia	1962.5

2.4 Geographic Information System

A GIS is a computer system for capturing, storing, querying, analyzing and displaying geospatial data. Geospatial data describes both the location and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geospatial data distinguishes GIS from other information systems. It also establishes GIS as a technology that can be applied for market research analysis and by environmental engineers. [8] [9].

2.4.1 Definition of GIS

There are many definitions that be used to describe the meaning of GIS. GIS can be defined as a collection of computer hardware, software, geography data, and institution that have been designed efficiently for collecting, keeping, provisioning, manipulation, analyzing and show all information that is referred to the geography coordinate (Goodchild, 1993) . Meanwhile GIS also can be defining as any manual or computer based set of procedures (Aronoff, 1989) which is used to keep and manipulate the data that have the geography references.

Similar to other information systems, GIS functions to enhance the capability of making decisions in research, management and planning. It involves processes from collecting data to analysis and re-producing useful information in decision making processes. Meanwhile Burrough (1986) defines GIS as a set of hardware that can collect, keep, get information back when required, analyze and display the spatial data in real word.

In conclusion, GIS can be defined as a combination of hardware and software to help analyze and display spatial and attribute processes in management and planning. The unique advantage of GIS is its capability to combine spatial and non spatial data and perform analysis on both components (Taher, B.1997) [9][10].

2.4.2 Component of a GIS

Taher B. (1997) classifies GIS to four fundamental components. If we look at the GIS development angle, there are hardware, software, data, and institution (Figure 2.1).

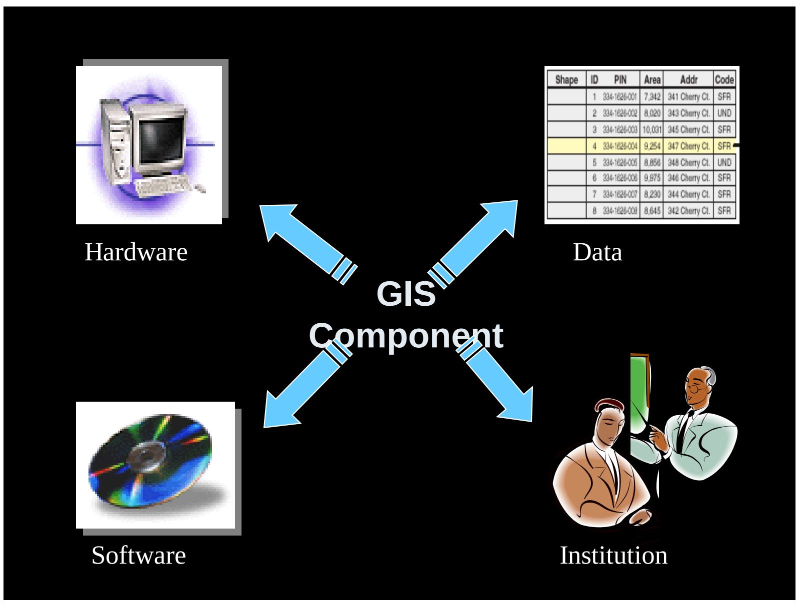


Figure 2.1 : Four GIS fundamental components.

2.4.2.1 Hardware

Hardware includes the computer on which the GIS operates on, the monitor where results are displayed and a printer for making hard copies of the results. The data files used in GIS are relatively large, so the computer must have a fast processing speed and a large hard drive capable of saving many files. Basically, GIS visual results need a large, high-resolution monitor and a high-quality printer [9][10]

2.4.2.2 Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components include tools for the input and manipulation of geographic information, a database management system (DBMS), tools that support geographic query, analysis, and visualization, and a graphical user interface (GUI) for easy access to tools [9].

2.4.2.3 Data

Data is the most important component of a GIS. The cost of collecting data consists of 70% from the total cost. It's shown data is the priority to the successful in GIS, especially in geographic data planning and management. GIS has two types of data such as attribute and spatial data. Attribute data is data that shows the quantity and quality of an object in graphics and spatial data is data that can be related to the ground surface and in a certain coordinate system such as latitude-longitude, planar coordinate system and Universal Transverse Mercator. Basically spatial data can be divided to the three fundamental shapes; point, line and polygon and can be displayed in vector and raster shapes [9].

2.4.2.4 Institution

The Institution is the people or organization that design, use and develop the GIS. It has the important role of ensuring that the implementation of GIS is efficient because they are responsible in managing, building and planning in order to solve geographic problems that occur in the real world. That is why the customer must have the expertise to develop and maintain the system as is required [9].

2.4.3 GIS Sub-System

GIS has four main sub-systems, which are data entry, data management, data analysis and data display (Aronoff, 1989). All this can be explained in two figures below (Figure 2.2 and 2.3),

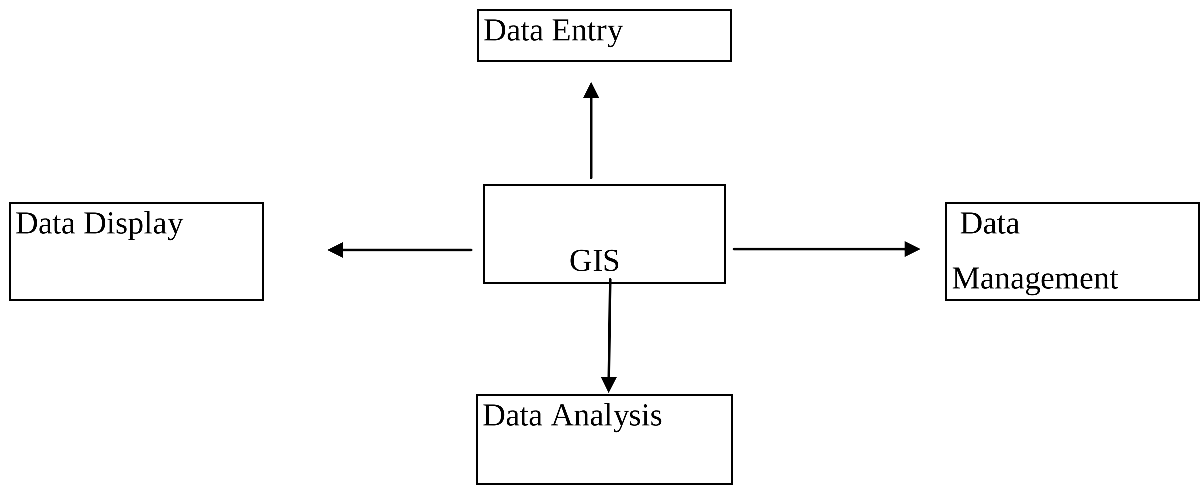


Figure 2.2: GIS Sub-System

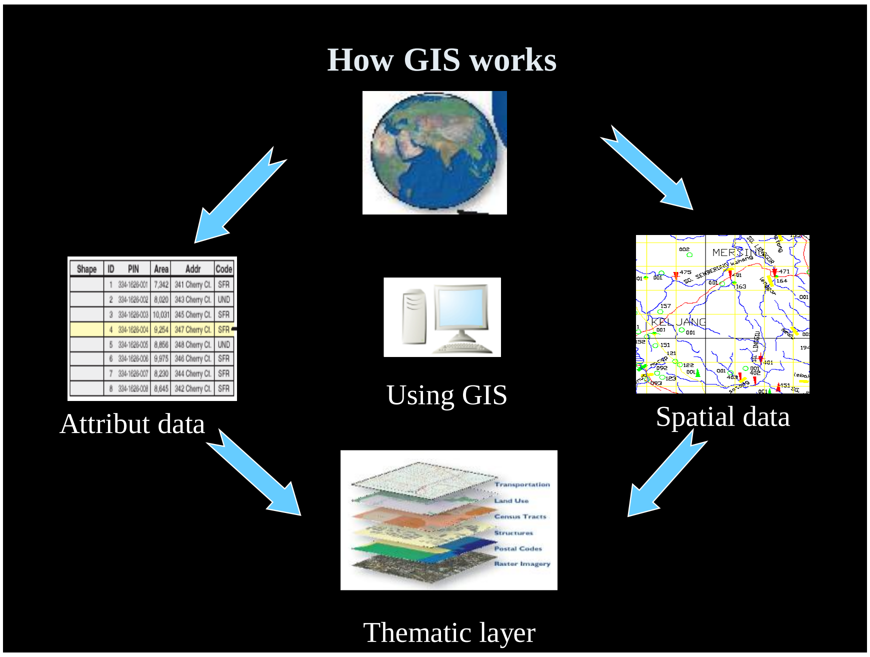


Figure 2.3 : The summary how the GIS works.

i) Data entry

The entry process will use attribute and spatial data. That data will be digitized so that it can be understood by the computer. This step basically provides instructions for entering, updating and correcting data. The data entry processes will involve three main aspects such as data processing, data quality and precision and the result.[9]

ii) Data Management

Data management involves the process of managing the database like storing data in a database, connecting topological data and updating and retrieving data. GIS software basically includes the management system known as a database management system (DBMS). DBMS is a system that has a set program which prepares the facilities for the manipulating and organizing of data in the database. The main characteristics of DBMS are connected to the data freedom, data dictionary, data structure, data retrieval, overflow control and customer overview (Ruslan et al, 1998). Meanwhile the DBMS also includes the data definition language, data-entry module, data update module, report generator and query language (Clarke, 1997)[9].

iii) Data Analysis

The analysis of data involves analyzing the stored data and producing a new data set. Analysis can be done on spatial and attribute data or a combination of the two sets of data. The capability and function of certain analysis are different with other systems. Meanwhile the precision and source of data will influence the quality of the analysis [9].

iv) Data Display

Data display is the last process. The result will be displayed either in hardcopy or softcopy. The analysis results in hardcopy are the map, figures and printed text and the analysis results in softcopy are the digital map and the attribute data [9].

2.5 Application of GIS in RFI Detection Site

GIS, with its array of functions, should be viewed as a process rather than as merely software or hardware. GIS is for making decisions. The way in which data is entered, stored, and analyzed within a GIS must mirror the way information will be used for a specific research or decision-making tasks. To see GIS as merely a software or hardware system is to miss the crucial role it can play in a comprehensive decision-making process[9][10][11].

Peninsular Malaysia has been selected as the study area in order to select the best site which is pinpointed as a possible site to build Malaysia’s first radio telescope. Peninsular Malaysia is bound between longitude (100^{o}19’0” - 104^{o}10’0”) E and latitude (1^{o}25’43” - 6^{o}39’56”) N.

The RFI site selection in Peninsular Malaysia will involve collecting geographical data related to various aspects or parameters such as the population of citizens, population density of citizens, communication transmitter station area data, road networks, and land contour data. A Peninsular Malaysia map at a scale of 1:1205,000 has been used as a base map. Various thematic maps have been prepared to use information from personally collected data from various agencies such as the Department of Statistics Malaysia, the Department of Meteorological Malaysia, the Malaysia Communication and Multimedia Commission and the Department of Survey and Mapping Malaysia.

When all information has been collected as required, GIS will be the medium for analysis and will assist in determining a few suitable areas for radio astronomical observation. The details about the GIS methodology system development will be discussed in Chapter 3.

2.6 Previous work on RFI

A literature study is made, in order to give some ideas on how to measure the RFI and find a suitable site. Several examples will be presented, each with its own purposes and methodology.

Rui Fonseca and their team have done research on site evaluation and RFI spectrum measurement in Portugal at the frequency range 0.408-10 GHz for Galactic Emission Mapping experiment (GEM). They probed for RFI at three potential GEM sites using custom made omni-directional discone antennas and directional pyramidal horn antennas. For the installation of a 10-m dish dedicated to the mapping of polarized galactic emission foreground planned for 2005–2007 in the 5–10 GHz band, the three sites chosen as suitable to host the antenna were surveyed for local radio pollution in the frequency range 0.01–10 GHz. Tests were done to look for mobile phone emission lines and radio broadcasting in the radio spectrum.

One of the sites, Castanheira da Serra shows good climatic conditions (low humidity, high number of good weather days, stable geography) and a very low RFI on the survey bands to host a GEM antenna. In this particular work, it clearly shows a clean radio spectrum, free of RFI spikes in the 5 GHz band down to -143 dBm sensitivity, close to the typical values of the expected polarized galactic [12][37].

Don Lawson, a senior RFI engineer at Jodrell Bank Observatory also performed RFI measurement at frequency 150-1750 MHz in Mediera, Portugal in order to choose the best site to build a new radio telescope. The radio telescope is a great opportunity to increase the quality of Very Long Baseline Interferometry (VLBI) observations. . Five items of work were identified as required in deciding the choice of a site to build a radio telescope. Measurements of radio interference have been carried out at the 3 recommended sites "Feiteiras de Baixo (A), "Pico da Faja da Lenha" (D), and "Fonte da Pedra – north" (G).

All 3 sites (G, D, and A) visited were measured for levels of Radio Frequency Interference (RFI) using a Rohde and Schwarz EB200 miniport receiver connected to a Rohde and Schwarz calibrated HK014 vertically polarized omni-directional antenna via a 6 m calibrated N type cable. The measurements at every single site consisted of 30 sweeps from 80 to 2000 MHz at 100 kHz steps and resolution bandwidth (rbw) of 120 kHz. It took 66 minutes for each full run at each site.

These are the same types of standard measurements carried out by Jodrell Bank Observatory (JBO) at existing or potentially new telescope sites. All the Madeira site RFI measurements are compared with measurements carried out in the same way at a ground level site at Jodrell Bank in 2003. As the result, Site A is worse than the Jodrell Bank site in some bands and appears to be the worst of the 3 prime sites from existing RFI measurements and from the potential for increasing risk of RFI from TV signals, mobile phones and gradual expansion of sources of RFI from people and buildings [13][38].

2.7 Radio Frequency Interference

In general terms, interference may be defined as follows: The effect of unwanted energy due to one or a combination of emissions, radiation, or induction upon the reception of a radio system manifested by the serious degradation, obstruction, or repeated interruption in communication. (Robert S. Mawrey, 1986). The radio frequency is a type of wave, which emits an electromagnetic field when alternating current is applied to an antenna. (Shimonski, 2002).

Based on the two definitions above, RFI can be defined as electromagnetic radiation that oscillates between the audio and infrared frequencies in the electromagnetic spectrum. The frequency band that we are interested in studying for this research is from very low frequency (*VLF*) to very high frequency (*VHF*), 10 kHz to 2060 MHz, respectively. RFI also can be defined as any "unwanted" signal that occurs and prevents the radio sources signals from space which is very weak to be collected by the radio telescope. [12][13].

2.7.1 Types and Sources of RFI

i- Conducted RFI

The various sources of conducted interference and the frequencies or range of frequencies at which their noise spectrum dominates are listed in Table 2.3 below. It has been established that electronic equipment has a conducted spectrum which stretches from the "lowest observable fluctuation rates" to above 1 GHz [14]. At high frequencies, "any wire that carries currents can act as a radiator and any conductor in the vicinity of an electromagnetic field can act as a receiving antenna or transmitting antenna"[15].

Table 2.3: Showed the various sources of conducted interference and the frequencies or range of frequencies [15]

Conducted	Frequency
Heater Circuits	50 KHz to 25 MHz
Lamps	0.1 to 3 MHz
Computer	50 KHz to 20 MHz
Command programmer signal lines	0.1 to 25 MHz
Power supply switching circuits	0.5 to 25 KHz
Power controller	2 to 15 kHz
Command programmer	0.1 to 25 MHz
Coil pulses	1-25 MHz
Contact cycling	50 KHz – 25 MHz
Transfer switch	0.1 to 25 MHz
Vacuum Cleaner	0.1 to 1 MHz
Magnet Armatures	2 to 4 MHz

ii- Radiated Interference

Radiation happens when electromagnetic energy is released from a source and propagates in space. This can either be intentional like in X-Ray and transmitter applications or unintentional like microwave ovens, incidental like automotive ignition systems and accidental such as nuclear disasters. Radiated interference happens when radiated energy causes the receiving devices, systems or equipment to malfunction or interferes with the normal functioning of the receiving devices, systems or equipment [14][15][16]. The sources of radiated interference can occur from a number of sources, which are listed in Table 2.4 below.

Table 2.4: Showed radiated interference from a number of sources [15].

Sources	Frequency
Harmonic Generator	30 MHz to 1000 MHz
Motor	10 KHz to 400 kHz
Teleprinter	1.8 MHz to 306 MHz
Transfer switch	15 kHz to 150 kHz
DC power switch	100 kHz to 30 MHz
Multiplexer solid-state switching	300 kHz to 500 kHz
Power wires	50 KHz to 4 MHz
Fluorescent Lamp	100 kHz to 3 MHz

2.7.2 Classes of RFI

It is important to know what is meant when talking about interference. Radio astronomers make passive use of the parts of the spectrum legally allocated to communication and other services. Figure 2.4 below indicates the band allocated for passive radio astronomy usage [12]. Radio-frequency interference may be generated either externally or internally with respect to the radio telescope. Externally-generated RFI may be from a natural or artificial source. Natural sources of RFI include the celestial (cosmic/galactic noise, solar noise) and terrestrial (atmospheric, lightning, electrostatic discharge) sources [6].

Artificial sources of RFI may be unintentional, such as electrical noise from car engines and microwave ovens or it may be intentional, such as communications, broadcasting and satellite applications. On the other hand, internal RFI is generated by the electrical equipment that usually is used in controlling the telescopes and processing the signals. Most internal RFI is caused by digital equipment such as computers, receivers, spectrum analyzers and other electrical circuits and components. This RFI will interrupt the signal that we want to observe. RFI of this type appears as a monochromatic signal at the fundamental and harmonic frequencies of the various clocks and data signals of the digital equipment. Usually, internally-generated RFI has been eliminated by placing most of the digital hardware within a Faraday cage [6][17].

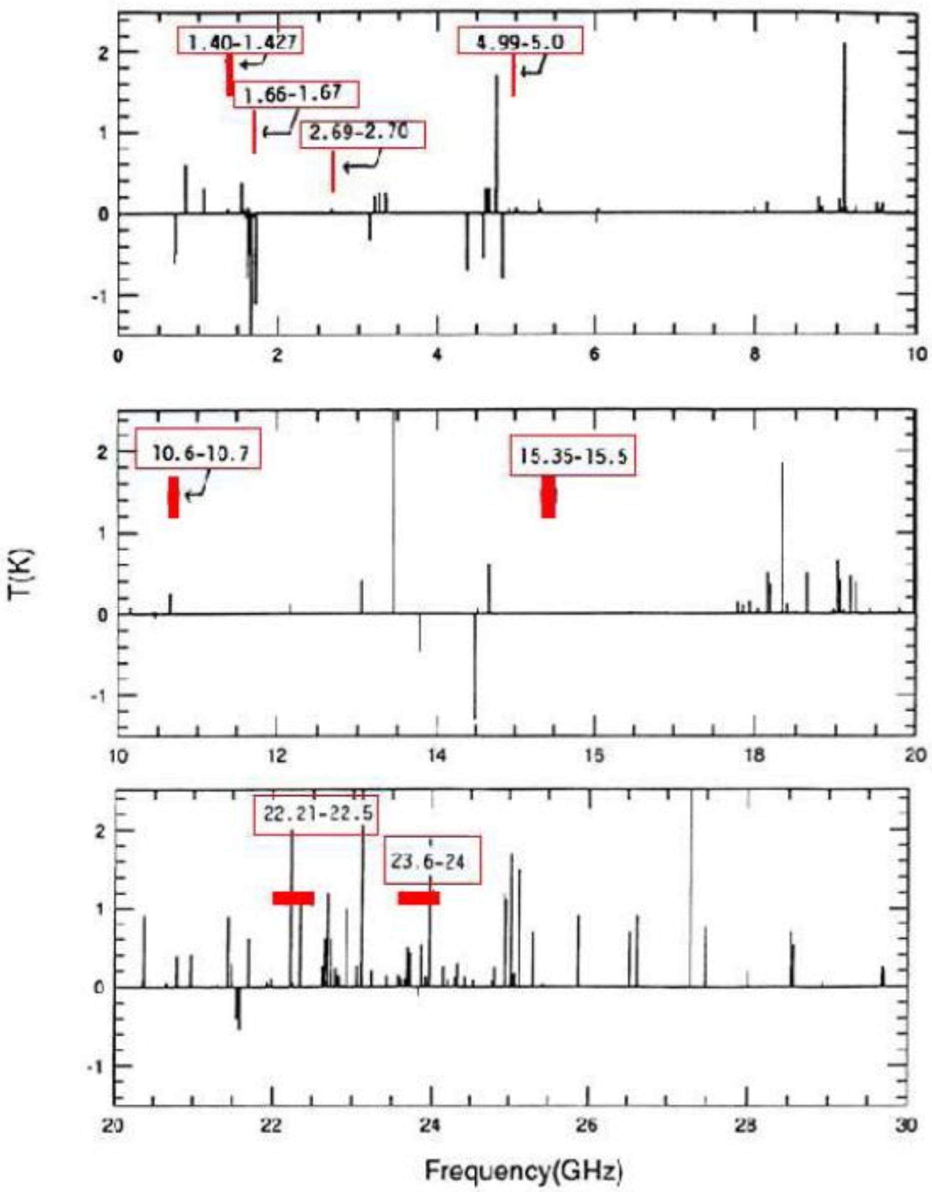


Figure 2.4: Spectral lines (at zero redshift) are indicated in absorption or emission from 0 -30 GHz. The boxes indicate the bands allocated for passive radio astronomy uses. Figure from Morimoto 1993.

2.8 Various Subsystem of the RFI Measuring System

The RFI measuring system contains several items that must be fulfilled. These combinations are very important to produce the RFI measurement in radio astronomy. The basic items in this combination are:

1. Antenna,
2. Spectrum analyzer
3. Low noise amplifier

2.8.1 Antenna

The antenna is the most crucial component of any receiving system. Therefore, design of this component and its proper selection is paramount. The purpose of an antenna is to convert radio-frequency electric current to electromagnetic waves, which are then radiated into space. Here, we define wavelength as the distance in free space traveled during one complete cycle of a wave. The velocity of a wave in free space is the speed of light, and the wavelength is thus: [18]

$$\lambda_{\text{meters}} = \frac{299.7925 \times 10^6 \text{ meters/sec}}{\text{f hertz}} = \frac{299.7925}{\text{f MHz}} \qquad (2.1)$$

where λ_{meters}, the Greek letter lambda, is the free-space wavelength in meters.

Expressed in feet, equation 2.1 becomes: [18]

$$\lambda_{feet} = \frac{983.5712}{fMHz} \approx \frac{983.6}{fMHz} \qquad (2.2)$$

2.8.1.1 Antenna Fundamentals

Through out this thesis some expressions common in the antenna industry, and in microwave engineering, will be used. For someone who has not heard these before, the meaning of these expressions might not be obvious. Therefore, a short presentation of some fundamental expressions found throughout this dissertation will follow. No matter what form an antenna takes, simple or complex, its electrical performance can be characterized according to the following important properties: [18].

1. Feed-Point Impedance
2. Directivity, Gain and Efficiency
3. Polarization

2.8.1.2 Feed-Point Impedance

The feed-point impedance is an important characteristic to define an antenna. Since we are free to choose our operating frequencies within assigned bands, we need to consider how the feed-point impedance of a particular antenna varies with frequency, within a particular band, or even in several different bands if we intend to use one antenna on multiple bands.

There are two forms of impedance associated with any antenna. First is self impedance and second is mutual impedance. Self impedance is what you measure at the feed-point terminals of an antenna located completely away from the influence of any other conductors. Mutual impedance is due to the parasitic effect of nearby conductors. This includes the effect of ground, which is a lossy conductor, but a conductor nonetheless. Mutual and self impedance can be defined using Ohm’s Law.

However, mutual impedance is the ratio of voltage in one conductor, divided by the current in another (coupled) conductor. The pattern of a highly directive antenna can be distorted by mutually coupled conductors, as well as the changing of impedance at the feed point [18][19][20].

2.8.1.3 Directivity, Gain and Efficiency

1-Antenna Directivity

The directivity of an antenna is the directivity of a non isotropic source is equal to the ratio of its radiation intensity in a given direction, over that of an isotropic source [18][19][20].

$$D = \frac{U}{U_i} = \frac{4\pi U}{P} \qquad (2.3)$$

Where;

D = the directivity of the antenna

U = the radiation intensity of the antenna

U_i = the radiation intensity of an isotropic source

P = the total power radiated

Sometimes, the direction of the directivity is not specified. In this case, the direction of the maximum radiation intensity is implied and the maximum directivity is given by:

$$D_{\max} = \frac{U_{\max}}{U_i} = \frac{4\pi U_{\max}}{P} \qquad (2.4)$$

where;

$D_{\max}$ = the maximum directivity

U_{max} = the maximum radiation intensity

The directivity of an antenna can be easily estimated from the radiation pattern of the antenna. An antenna that has a narrow main lobe would have better directivity, then the one which has a broad main lobe [18][19][20].

2-Antenna Gain

The gain of an antenna in a given direction is the amount of energy radiated in the direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain and the direction in which the antenna is radiating most of the power [18][19][20].

An antenna with a large aperture has more gain than a smaller one. As it captures more energy from a passing radio wave, it also radiates more energy in that direction. Gain may be calculated as

$$\mathbf{G}_{\mathrm{dBi}} = 10\log\left(\eta \frac{4\pi}{\lambda^2} A\right) \qquad (2.5)$$

with reference to an isotropic radiator ; η is the efficiency of the antenna , A is area and λ is wavelength[18][19] [20].

3-Antenna Efficiency

The antenna efficiency is the amount of losses at the terminals of the antenna and within the structure of the antenna. These losses are given by:

• Reflections because of mismatch between the transmitter and the antenna

• I^2R losses (conduction and dielectric) where I is current and R is resistance.

Hence the total antenna efficiency can be written as:

$$E^t = E^a E^b E^c \quad (2.6)$$

where

E^t = total antenna efficiency

$E^a = (1- |\Gamma^2|)$ = reflection (mismatch) efficiency

E^b = conduction efficiency

E^c = dielectric efficiency

Since E^b and E^c are difficult to separate, they are lumped together to form the E^{bc} efficiency which is given as:

$$E^{bc} = E^b E^c = \frac{R_r}{R_r + R_L} \quad (2.7)$$

E^{bc} is called as the antenna radiation efficiency and is defined as the ratio of the power delivered to the radiation resistance R_r, to the power delivered to R_r and R_L [18][19][20].

2.8.1.4 Polarization

When we talk about polarization, it refers to the polarization of electromagnetic waves. An electromagnetic wave has an electric field component, $\vec{E}$, and a magnetic field component, $\vec{H}$. These components are perpendicular to each other, and they are also perpendicular to the wave's direction of propagation. An electromagnetic wave travels in the same direction as Poyntings vector, which is defined as:

$$\mathbf{P} = \frac{1}{2} \quad \vec{E} \text{ x } \overrightarrow{H} \tag{2.8}$$

Vertical polarization means that the electric field is vertically orientated and horizontal polarization means that the wave has an electric field component in the horizontal plane. The polarization of an antenna is defined as the polarization of the wave radiated when the antenna is excited. A dual polarized antenna is an antenna that is independent of the incident waves polarization. An antenna can also be circularly polarized. This occurs when the two components have equal magnitude and the time-phase differences between them are odd multiples of $\pi/2$. If the magnitudes are different, elliptical polarization is obtained. [18][19] [20]

If the path of the electric field vector is back and forth along a line, it is said to be linearly polarized. Figure 2.5 shows a linearly polarized wave. In a circularly polarized wave, the electric field vector remains constant in length but rotates around in a circular path. A left hand circular polarized wave is one in which the wave rotates counter clocks whereas right hand circular polarized wave exhibits clockwise motion as shown in Figure 2.6.

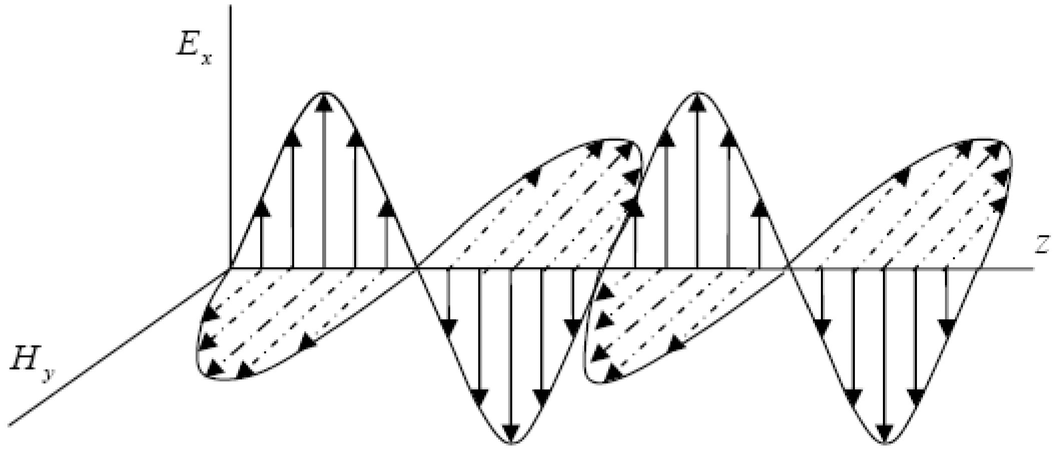


Figure 2.5; A linearly (vertically) polarized wave

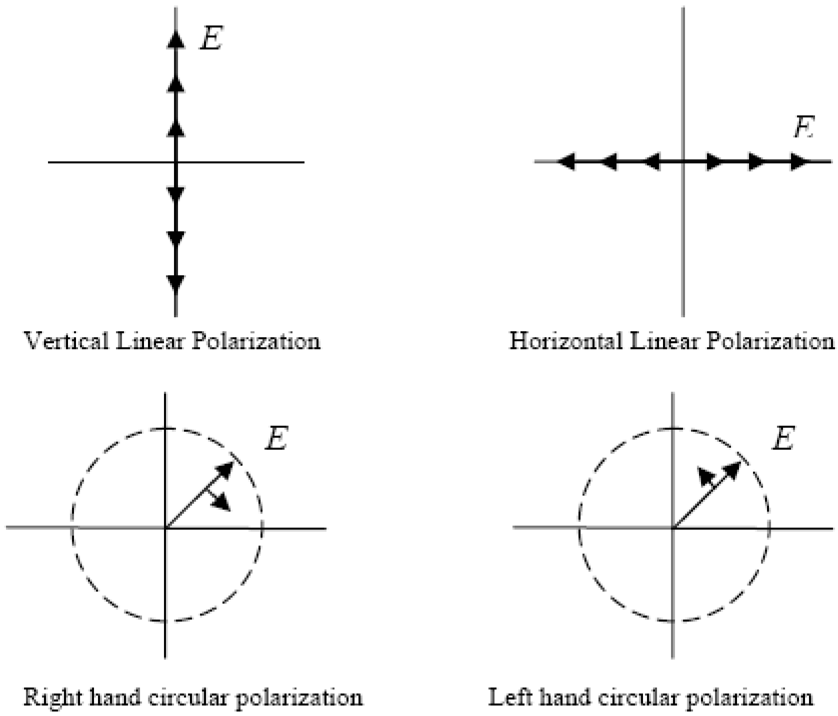


Figure 2.6: Commonly used polarization schemes

2.8.2 Aperture

The aperture of an antenna is the area that captures energy from a passing radio wave. For a dish antenna, it is not surprising that the aperture is the size of the reflector and for a horn the aperture is the area of the mouth of the horn. Wire antennas are not so simple. A thin dipoles has almost no area but its aperture is roughly an ellipse with an area of about $0.13\lambda^2$ and Yagi-Uda antennas have even larger apertures [18][19] [20].

2.8.3 Discone Antenna

In order for the radiation pattern of an antenna to be omnidirectional it should essentially have a nondirectional pattern in the azimuth plane [$f(\varphi)$, θ = *constant*] and directional in the elevation plane [$g(\theta)$, φ = *constant*] (see Figure 2.7). In other words, in order to have an omnidirectional pattern the antenna should have the same directivity in all directions in the horizontal plane.[19][20][21]

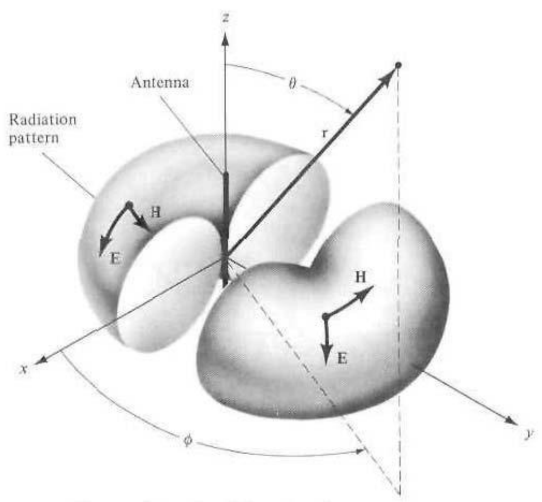


Figure 2.7; Omnidirectional radiation pattern, (C. Balanis)

Discone antenna is a very small antenna but very effective. It is vertically polarized and has an omni-directional radiation pattern .This antennas radiation pattern is essentially the same as that of a linear dipole, and its polarization is vertical. The fields are given by Equation 2.9 and Equation 2.10. [21]

$$E_\theta \approx j\eta \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right)-\cos\left(\frac{kl}{2}\right)}{\sin\theta}\right] \tag{2.9}$$

$$H_\phi \approx j \frac{I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right)-\cos\left(\frac{kl}{2}\right)}{\sin\theta}\right] \tag{2.10}$$

where H_ϕ is the magnetic field , E_θ is the electrical field, I_0 is electric current , r is radius and η is radiation efficiency.

The discone is formed by a circular disc and a cone, both made out of metal, and it has a coaxial feeding (see Figure 2.8). The center conductor is connected to the disc, and the cones apex is connected to the outer shield of the coaxial line. The distance between the disc and the top of the cone should be kept as small as possible, without the two components touching each other. The disc is the part of the antenna that radiates the electromagnetic waves, and the cone works as a sort of ground plane, and it helps steering the radiated field towards the horizontal plane. The current distribution on the discone antenna can be seen in Figure.2.9, which is a picture obtained from computer simulations [21].

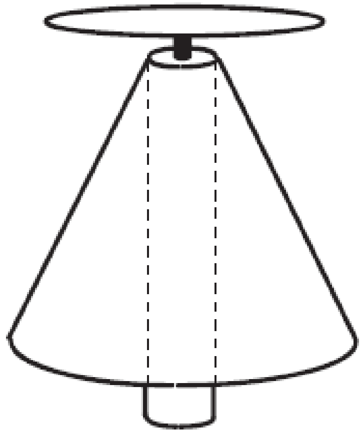


Figure 2.8: Discone antenna with vertical polarized having a 50Ω feed, with the inner conductor connected to the radiating disc, and the outer shield connected to the cone [21]

Figure 2.9: Current distribution on the discone antenna. [21]

While constructing the discone antenna, the length of cone element (L) and disc diameter (D) is dependent on the lowest frequency (F_{MHz}). It is based on the equations below. (see Figure 2.10) [22].

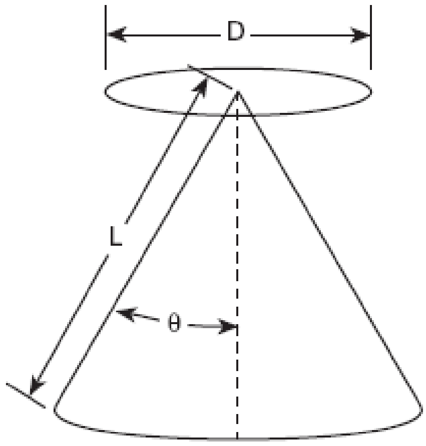


Figure 2.10: Discone antenna equation

$$L_{inch} = \frac{2963}{F_{MHz}} \tag{2.11}$$

$$D_{inch} = \frac{2008}{F_{MHz}} \tag{2.12}$$

.2.9 Amplifier

There are three categories of amplifiers i.e. low noise amplifier (LNA), power amplifiers and IF amplifiers. The latter has been used in the IF stage. Important design considerations include the power gain, intercepts and the noise figure (which is the noise factor expressed in decibels). In this research we only use LNA to amplify the sensitivity of RF analyzer to detect quantity weak signal from the outer space [3][23].

2.9.1 Low Noise Amplifier (LNA)

The LNA in radio astronomy actually acts as a preamplifier. The LNA is directly connected to the feedhorn, which is mounted over a radio dish antenna. Thus, the signal collected by the feedhorn gets amplified by the LNA. In this research, we purchased a LNA for the frequency operation 1420 MHz from Radio Astronomy Supplies (RAS). The LNA is already calibrated for that frequency by RAS. The example of the schematic diagram for the 1420 MHz LNA from Down East Microwave Inc. is shown below (see Figure 2.11) [3][23]

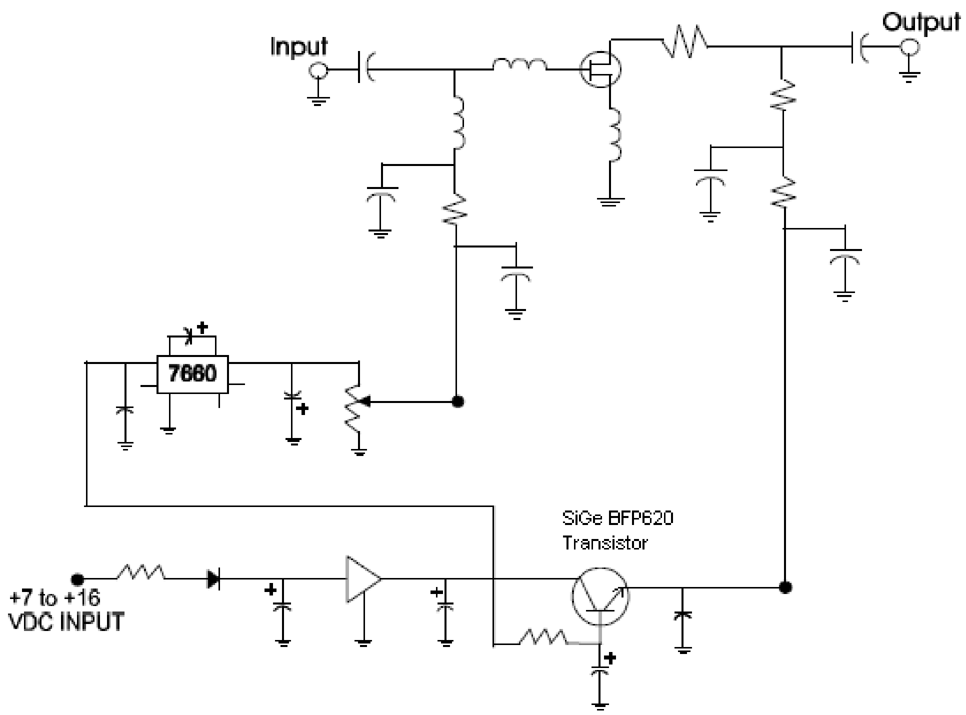


Figure 2.11: The LNA schematic diagram circuit for frequency 1420 MHz [24][39].

2.10 Spectrum Analyzer Theory

A spectrum analyzer is a measuring instrument for the analysis and measurement of signals throughout the electromagnet spectrum and displays an electrical signal according to its frequency. Basically each frequency component contained in the input signal is displayed as a signal level corresponding to that frequency. The Spectrum analyzer resolves a signal into its discrete frequency components and measures the power associated with each and every particular unit of frequency of the signal. The resolving power of the spectrum analyzer is governed by the resolution bandwidth (RBW) IF filters [15][25].

The spectrum analyzer is optimized to analyze a signal from radio frequency equipment. The minimum sensitivity of the spectrum analyzer is the minimum level of an input signal which causes a 3-dB change in the noise level as viewed on the display of the analyzer [25]. This is also called the minimum detectable signal. The maximum sensitivity is attained by setting the attenuation to 0 dB, minimizing the RBW, using log power averaging and connecting a high gain, low noise pre-amplifier to the spectrum analyzer [26]. High sensitivity of the analyzer is especially important for applications in which the resolution bandwidth is prescribed by standards.

2.10.1 Spectrum Analyzer Operation.

The spectrum analyzer usually contained super heterodyne receiver as the principle to build the spectrum analyzer. The main components of Spectrum Analyzer are an RF input attenuator, input amplifier, mixer, IF amplifier, IF filter, envelope detector, video filter, local oscillator (LO) and sweep generator. Figure 2.12 below shows the classic superhyterodyne spectrum analyzer block diagram [27].

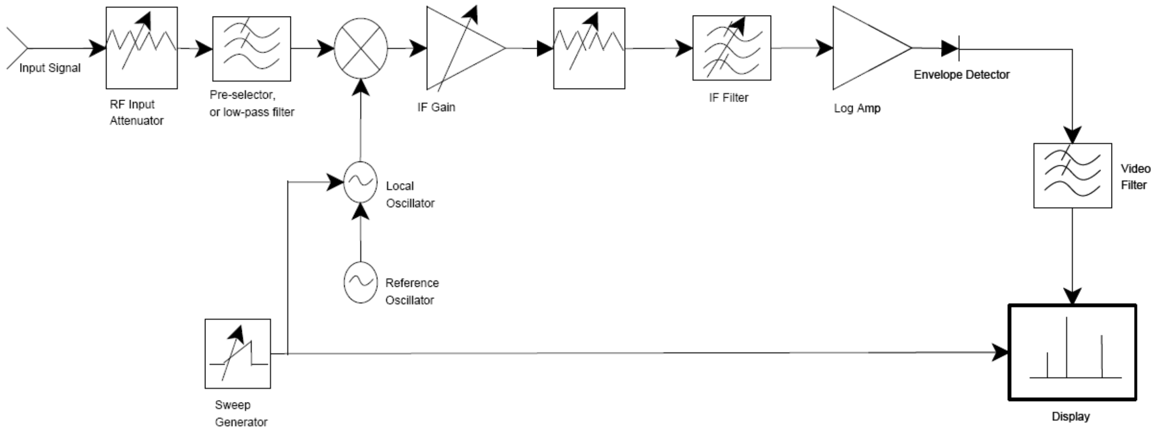


Figure 2.12: Block diagrams of a classic superheterodyne spectrum analyzer (from [15, 28, 29]).

A perfect receiver would add no additional noise to the natural amount of thermal noise present in all electronic systems, represented by:

$$N = kT\,B \tag{2.13}$$

where N is the noise power, k is Boltzman's constant, T = temperature in Kelvin degree, and B is the bandwidth of the system in Hz.

In practice, all receivers, including spectrum analyzers, add some amount of internally generated noise [27]. Spectrum analyzers will usually characterize the noise by specifying the displayed average noise level in dBm, with the smallest RBW setting. An input signal below this noise level cannot be detected. Generally, sensitivity is on the order of -90 dBm to -145 dBm depending on quality of spectrum analyzer. It is important to know the sensitivity capability of your analyzer in order to determine if it will measure your low-level signals.

However, the RF input attenuator does affect the signal level at the input and therefore decreases the signal-to-noise ratio (SNR) of the analyzer. The best SNR is with the lowest possible RF input attenuation. This internally generated noise in a spectrum analyzer is thermal in nature; that is, it is random and has no discrete spectral components. Also, its level is flat over a frequency range that is wide in comparison to the ranges of the RBWs. This means that the total noise reaching the detector (and displayed) is related to the resolution bandwidth selected (see Figure 2.13) [27] [30].

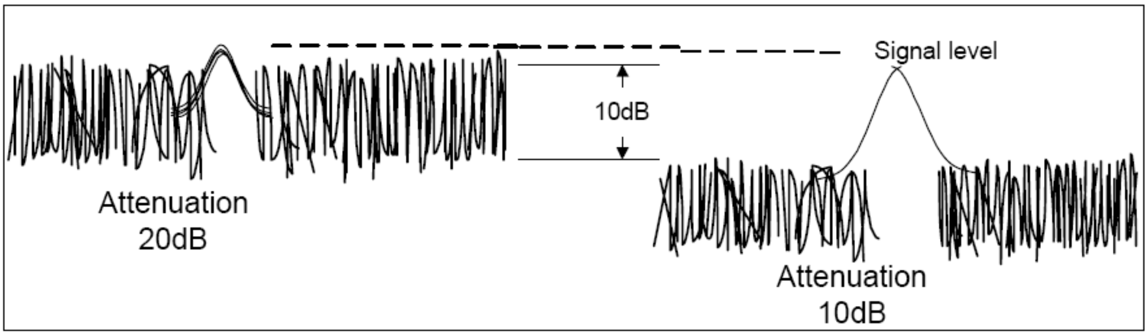


Figure 2.13: Showed SNR decrease as input attenuatuation increase

Chapter 3

Implementation of GIS Technique in Radio Astronomy Observation Selection Site

In this chapter, an implementation of GIS software will be discussed. GIS was applied in this study. GIS is a computer-based tool for mapping and analyzing events that happen on the earth surface. It can display the information in the form of graphics correlated with data. This is so that the user can make a better decision with limited data. The proposed methodology for site selection based on RFI parameter's criteria will be applied to find the suitable site for radio astronomical observation in Peninsular Malaysia. This section includes how GIS works, how to design a system, how to develop that system and how GIS can select the suitable site for radio astronomy observation.

3.1 Study Area

Peninsular Malaysia (longitude 100^{o} 19’ 0” E to 104^{o} 10’ 0” E and latitude 1^{o} 25’ 43” N to 6^{o} 39’ 56” N) (see Figure 3.1) was selected as the research area for this research in order to select the best site which is pinpointed as a possible site to build Malaysia’s first radio telescope. The main parameter for radio astronomy observation selection site is the sites that have very low RFI. The Peninsular Malaysia covers an area of about 131600 km^2 and contains 11 states including Perak, Pahang, Selangor, Kedah, Terengganu, Kelantan, Johor, Melaka, Negeri Sembilan, Perlis and Pulau Pinang.

States	Population (people)	Area (km^2)
Selangor	4 188 876	7 960
Johor	2 740 625	18 987
Perak	2 051 236	21 005
Pahang	1 288 376	35 965
Terengganu	898 825	12 955
Kelantan	1 313 014	15 024
Melaka	635 791	1 652
Negeri Sembilan	859 924	6 644
Perlis	204 450	795
Pulau Pinang	1 313 449	1 031
Kedah	1 649 756	9 425

Table 3.1: Table shows the population and the area in each state in Peninsular Malaysia. (Sources: Department Statistic of Malaysia, 2000)

The capital city of Malaysia is Kuala Lumpur. The population is approximately around 27 millions. Peninsular Malaysia is bordered by Indonesia, Thailand and Singapore. This country is located near the equator and experiences a tropical climate. The country is generally warm throughout the year with temperatures ranging from 21^{o} to 32^{o} Celsius in the lowlands. This can, however, be as low as 16^{o} Celsius in the highlands. Annual rainfall is heavy at 2500mm. On a rainy day thunder and lightning often accompany the heavy downpour which normally lasts for about an hour or two. Generally, Malaysia has two distinct seasons. The dry season occurs during the South-west monsoon from May until September. The Northeast monsoon brings the rainy season to the country during mid-November until March [31].

The development of Radio Astronomy field in this country is new. Due to this, Peninsular Malaysia was selected as the study area of radio astronomical observation selection site. The high places shown in Figure 3.1 are the mountains and hills located in Peninsular Malaysia.

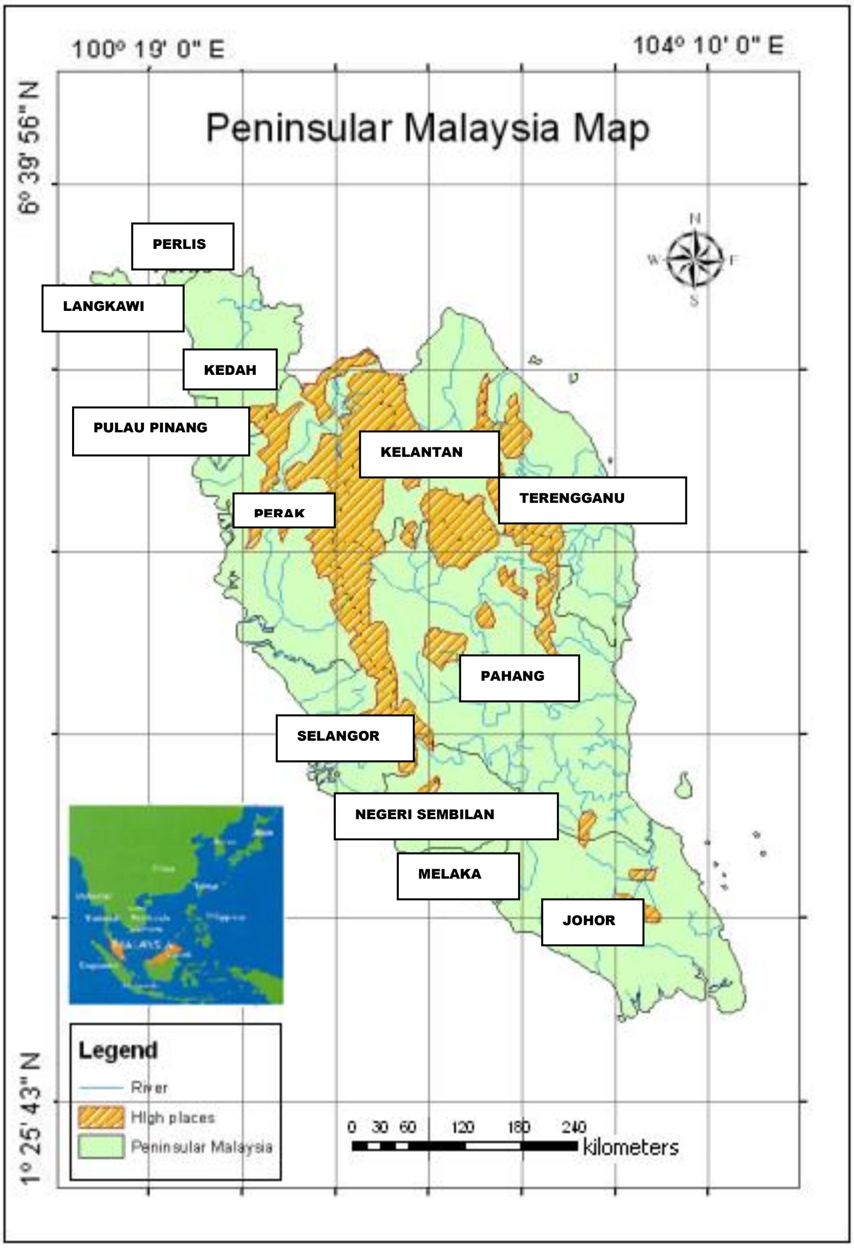


Figure 3.1: Research area for radio astronomical observation selection site.

3.2 Methodology of System Development.

The development of the GIS system requires several steps such as data collection, data entry, system design, system development, system testing and system analysis. The methodology chart for system development is shown in Figure 3.2 below.

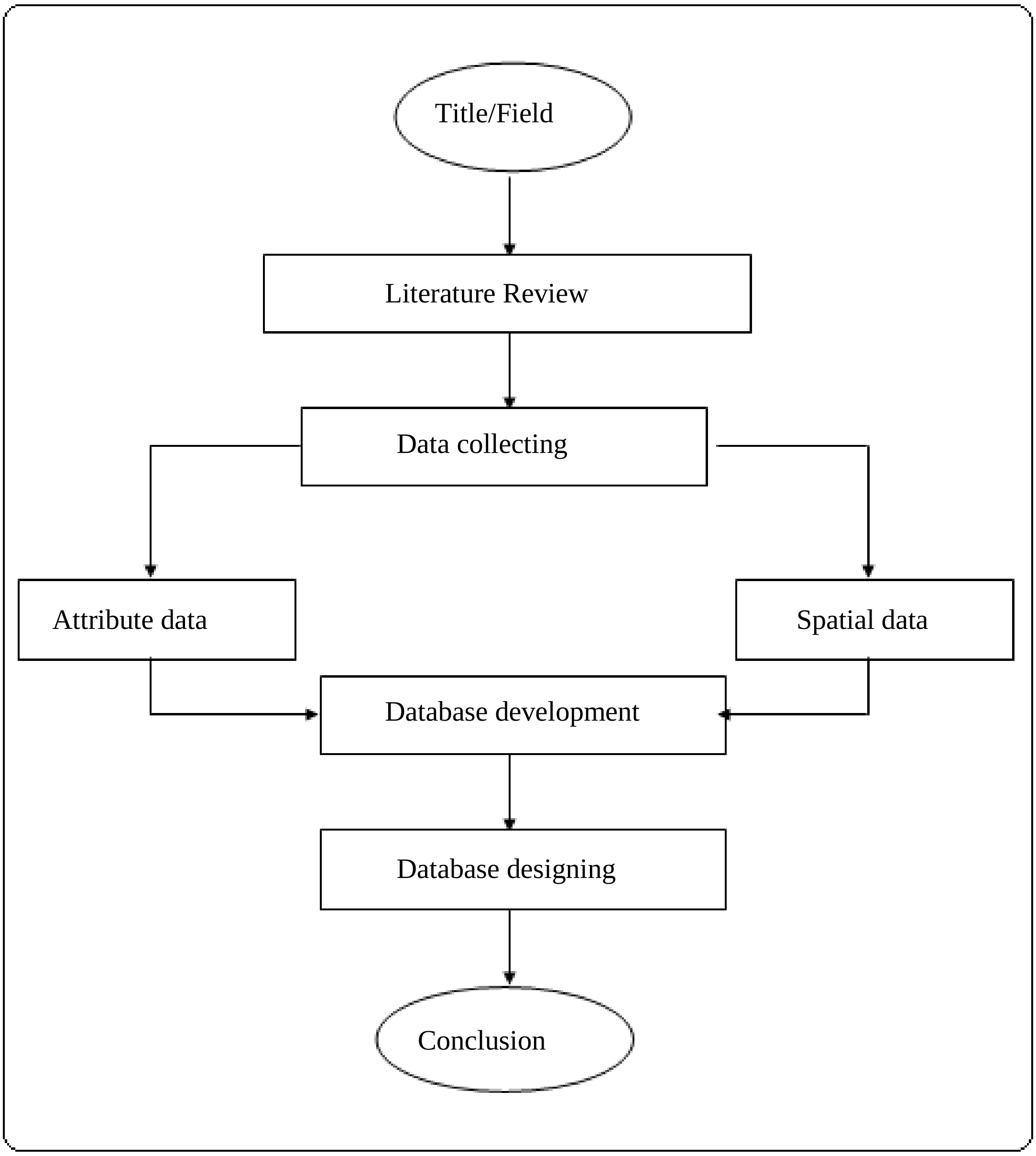


Figure 3.2: Methodology chart for System Development.

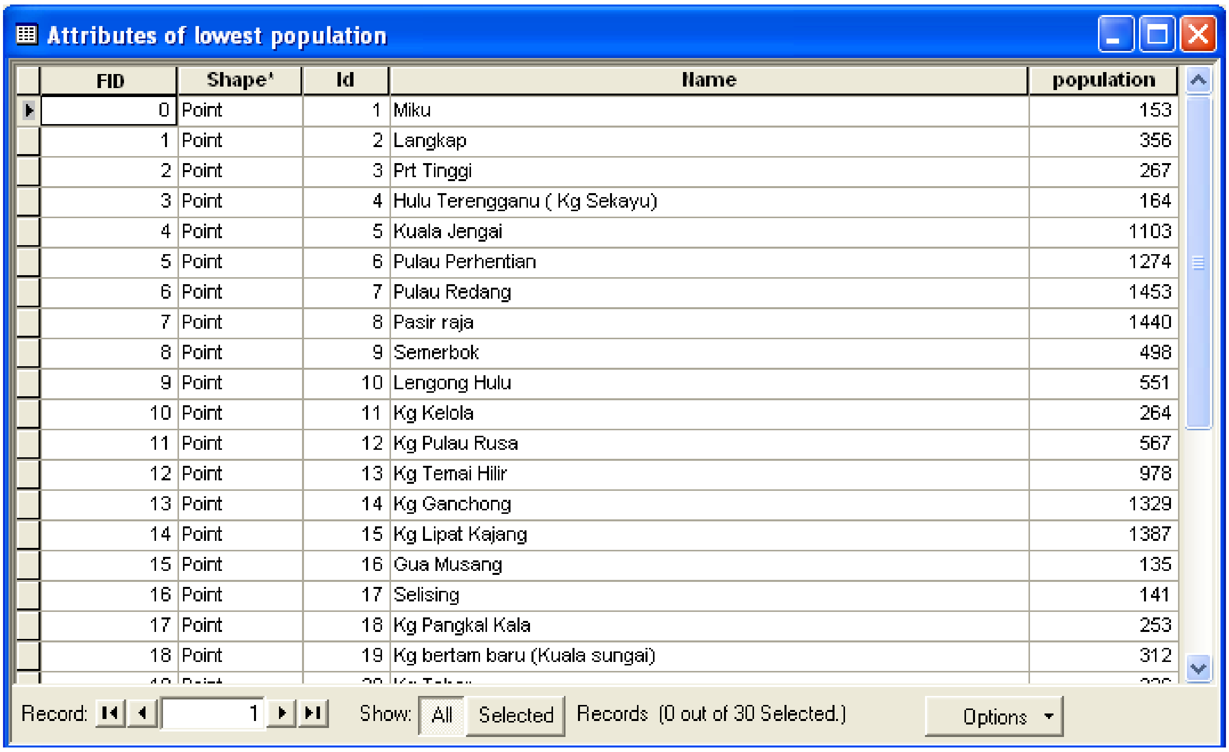
3.3 Data Collecting and Information.

The main parameter for radio astronomy observation site is the sites that have very low RFI. The parameters that have been chosen are the population of the citizens, the population density of the citizens, communication transmitter station's area data, road network, and land contour data. The data was collected from various agencies such as Department of Statistics Malaysia, Department of Meteorology Malaysia, Malaysia Communication and Multimedia Commission (MCMC) and Department of Survey and Mapping Malaysia. The data includes spatial and attribute data. Spatial data consists of maps of Peninsular Malaysia that we have obtained from the Department of Survey and Mapping Malaysia. A scanner was used to scan paper based maps. Other sources of spatial data include topography maps for high places in Peninsular Malaysia and GIS maps obtained from the previous study.

Meanwhile the attribute data consists of population data (see Figure 3.3) and population density data of Peninsular Malaysia. This data was collected from the Department of Statistics Malaysia. Meanwhile the rainfall data from the Department of Meteorology Malaysia is also used for this research. Eventually, the data from the communication transmitter station's are collected from the Malaysia Communication and Multimedia Commission (MCMC). All of these data are very important and useful for finding the site that has very low RFI levels.

Table 3.2: Tables shows the types of data and the sources of data.

Data	Sources of Data
RFI	Primary data from fieldwork
Map	Secondary data from Department of Maps and Measurements of Malaysia
Transmitter Location	Secondary data from Malaysia Communication and Multimedia Commission (MCMC)
Population and population density	Secondary data from as Department of Statistics Malaysia



Attributes of lowest population

FID	Shape*	Id	Name	population
0	Point	1	Miku	153
1	Point	2	Langkap	356
2	Point	3	Prt Tinggi	267
3	Point	4	Hulu Terengganu (Kg Sekayu)	164
4	Point	5	Kuala Jengai	1103
5	Point	6	Pulau Perhentian	1274
6	Point	7	Pulau Redang	1453
7	Point	8	Pasir raja	1440
8	Point	9	Semerbok	498
9	Point	10	Lengong Hulu	551
10	Point	11	Kg Kelola	264
11	Point	12	Kg Pulau Rusa	567
12	Point	13	Kg Temai Hilir	978
13	Point	14	Kg Ganchong	1329
14	Point	15	Kg Lipat Kajang	1387
15	Point	16	Gua Musang	135
16	Point	17	Selising	141
17	Point	18	Kg Pangkal Kala	253
18	Point	19	Kg bertam baru (Kuala sungai)	312

Record: 1 Show: All Selected Records (0 out of 30 Selected.) Options

Figure 3.3 : Attribute data for lowest population in Peninsular Malaysia.

3.4 Database Development

Firstly, the spatial data, 1:1205, 000 -scaled maps, digital maps and the attribute data were collected. The parameter criteria used in this study are the population of citizens, the population density of citizens, location of transmitter station's data, road network, and the land contour data.

1) Population

Population was selected as the parameter because RFI is basically caused by the human being indirectly. For example, an oven that is used by people will cause an RFI at frequency 2.4 GHz [6]. Furthermore, the electrical equipment such as television and computers will produce an RFI at the low frequency. The population site's data are obtained from Department of Statistics Malaysia. We select five moderate population areas (150-200 people) in each state for the beginning. After that we select the lowest population areas (less than 150 people) as the GIS perimeters in this research. We assumed, the site that has the smallest population has the minimum level of RFI. However, it must be connected to another parameter to get a suitable site [2][32].

2) Population Density

Population density is defined as the population per kilometer area, and it is connected to the population. In this case, the lowest population density is indicated by lower than 50 people per kilometer. Even if a site is included in the lowest population site, but if the population density is high, we cannot consider that site as the lowest RFI site. Basically, the sites that have the lowest population density are sites located in the rural area. [2][32].

3) Transmitter’s Location.

The selection of the transmitter’s location as the parameter is important because the signal from the transmitter is the major source of RFI such as the signal from communication, telecommunication, broadcasting and aerospace. The transmitter location data is important to find the site that has very low RFI levels. (Note: A typical cell phone (1 W transmitter) with a 10 kHz bandwidth at 1 km is a 10^{16} Jansky (Jy) (1Jy = 10^{-26} W/m2/Hz) source. These are 5×10^{12} times stronger than the brightest astronomical radio source at the same frequency (the supernova remnant Cassiopeia A, ~6000 Jy),and 10^{19} times stronger than the typical source observed with today's radio telescopes; according to Ron Maddalena, an astronomer at National Radio Astronomy Observatory(NRAO) [2] [5][32][33].

4) Road Network.

   This parameter is important to reach the selected site. It determines if the construction of the radio telescope in the selected site will be performed. A proper road network is crucial even though a particular site has the lowest RFI level.

5) Land Contour

   This parameter is important and the observation must not be located in the highlands. Our analysis has shown that the highlands will produce high RFI levels.

The potential site for each parameter was created. Finally, the parameters that contribute to the RFI level were applied to find the suitable site for radio astronomical observation in Peninsular Malaysia. The framework of site selection is shown in Figure 3.4.

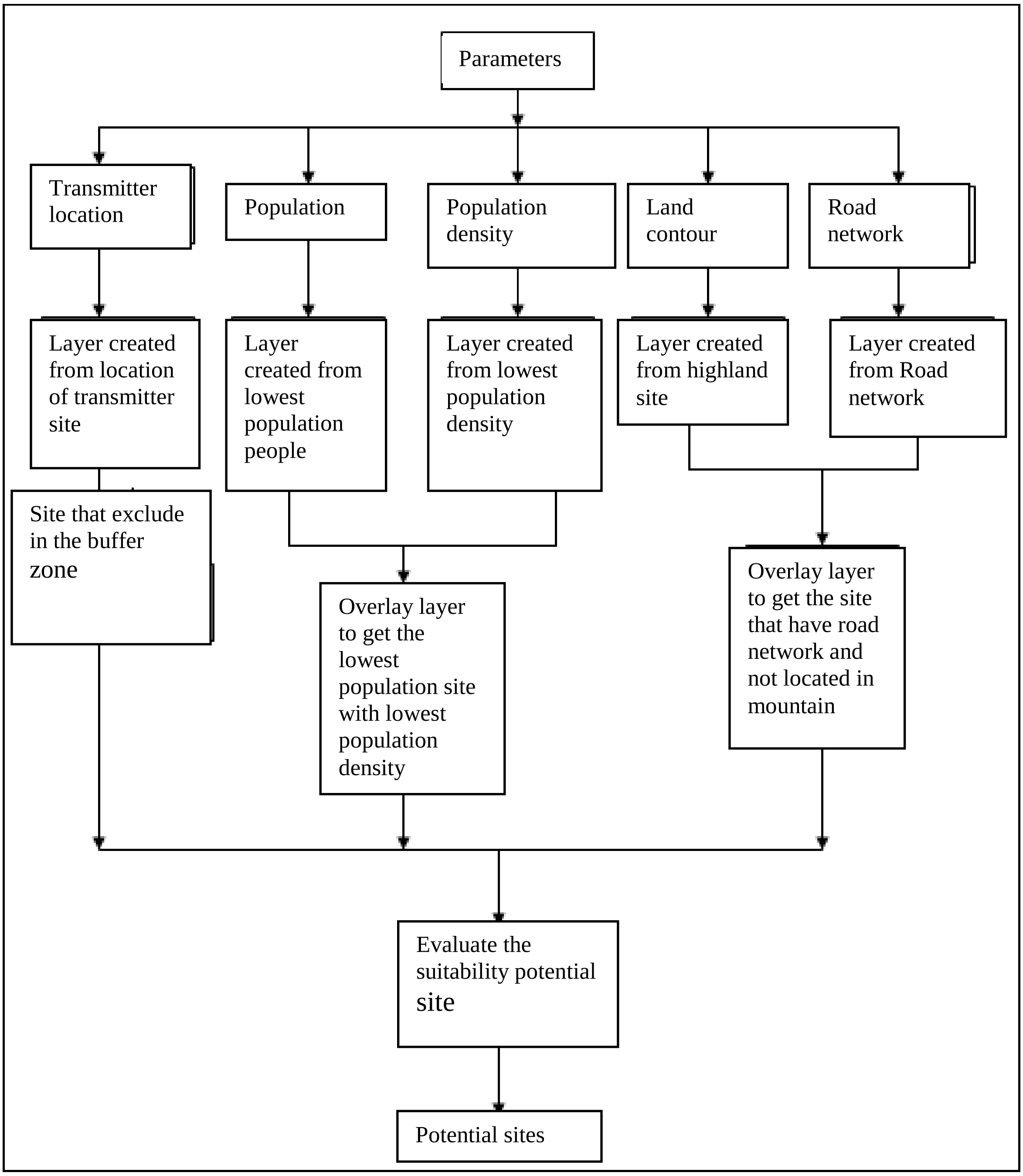


Figure 3.4 : Frame work of radio astronomy observation selection site.

3.5 Database Designing

The operation of database which is related to database concepts will be developed for this work. For our database design, it will involve entities such as:

3.5.1 Conceptual Designing.

The fundamentals components in relationship entity model or relationship figure are shown below (Figure 3.5):

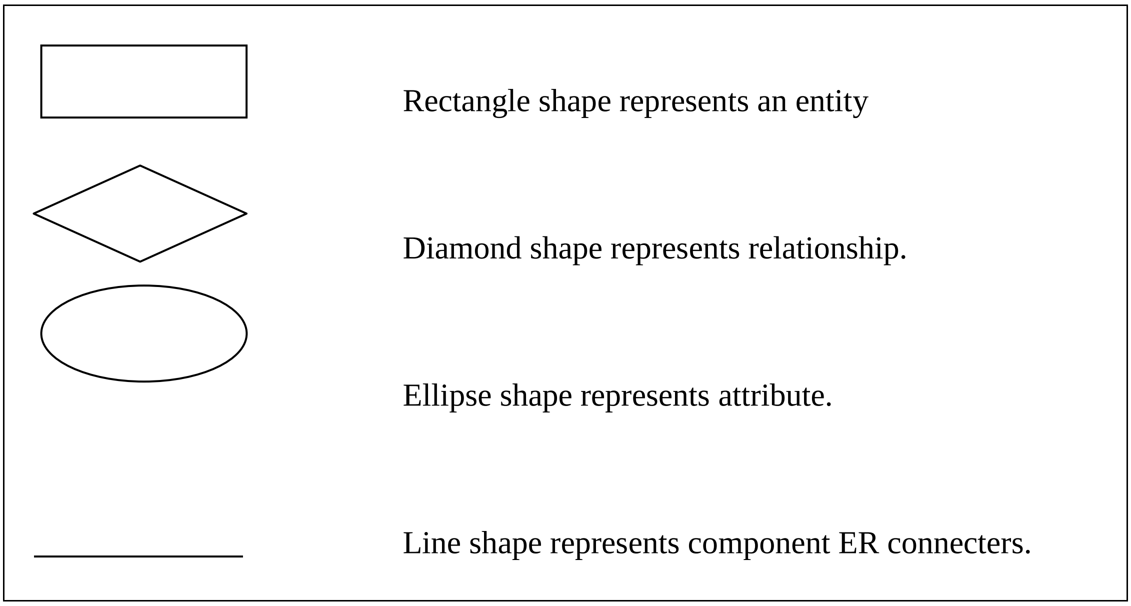


Figure 3.5: Fundamental components in Relationship model

Meanwhile, an entity relationship will be produced for the database that has been developed. The output of the conceptual designing was Peninsular Malaysia map entity and RFI data. The conceptual designing is only the overview about how the database will be connected between each other. Figure 3.6 below shows the entity relationship between all the entities in this research.

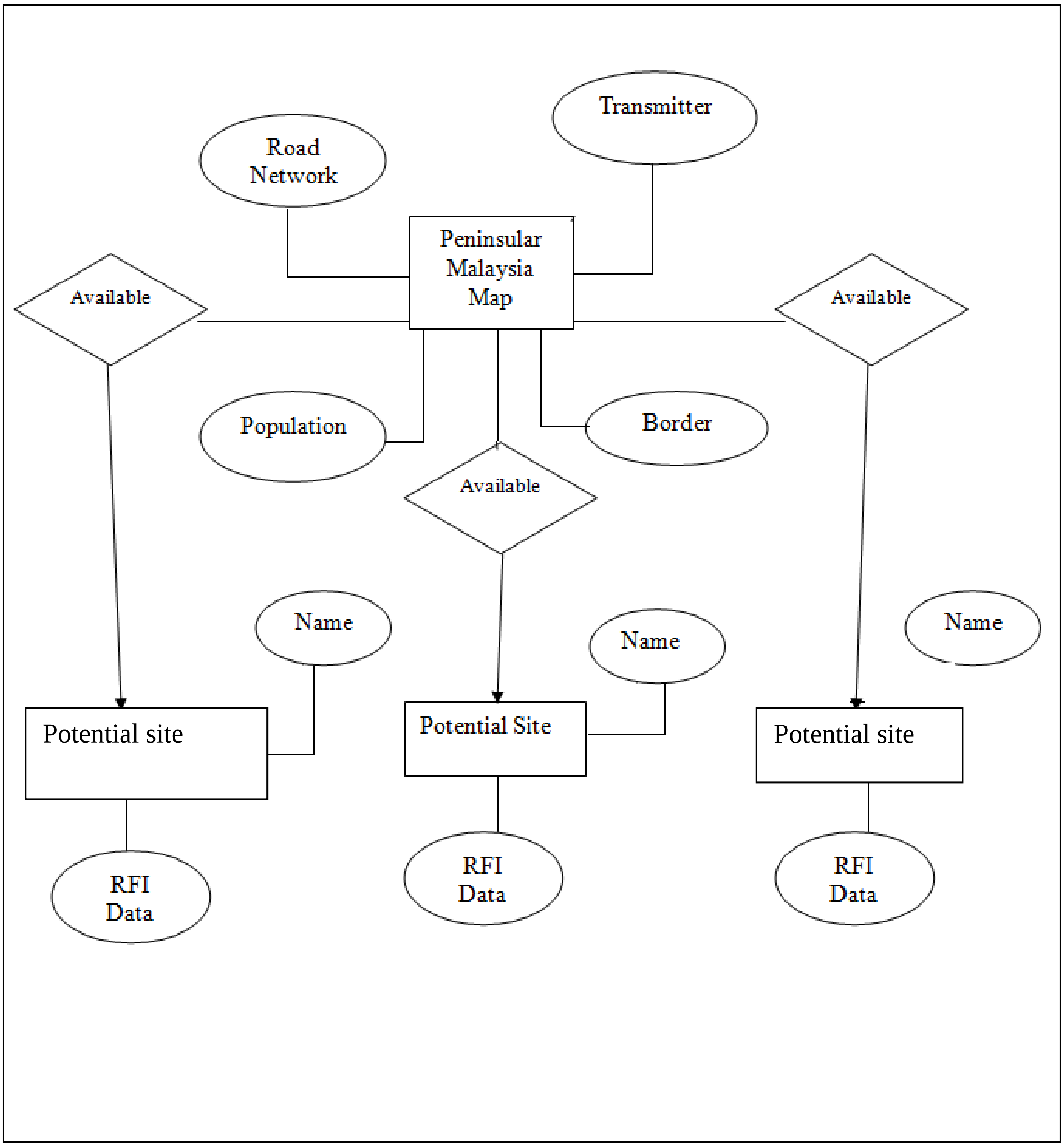


Figure 3.6: Entity Relationship Diagram

3.5.2 Logical Designing

After all the data was collected, a database will be developed and will be managed. This database will use a relationship data model or relationship database.

In logical designing, the attribute will have their field name, field type, field width and size (see Figure 3.4).

Field_Name	Field_Types	Field_Width	Saiz_data (bytes)
Lowest Population Site	Text	16	16
Population	Long Integer	16	16
Transmitter location	Text	16	16
Boarder	Text	16	16

Table 3.4: Logical Designing for Radio Astronomy selection site data layer

3.5.3 Relationship Between Spatial Data and Attribute Data

In the ArcGIS 9.3 (latest version), the attribute data will be saved and will be connected with spatial data using the RFI data observation station. The different data sets will be saved in layer concept in which each layer contains different information. A layer is a collection of all the features in the map that share some common characteristic. In this research several layers were used such as the Peninsular Malaysia map, road network, transmitter location, lowest population, lowest population density and buffer zone. Actually, a layer of the Peninsular Malaysia map, transmitter location and population density map are adequate to do the analysis. However, to get a specific and precise analysis other layers were used.

3.6 Spatial and Attribute Data Entering Procedures

3.6.1 Importing Spatial Data into Arcview

Before entering the spatial data into Arcview, the concept of spatial data is based on layer by layer where the different data will be arranged according to their purposes. In this research, there are 5 layers that have been used such as the

Peninsular Malaysia map boarder, road network, transmitter location, lowest population and lowest population density. Figure 3.7 shows the layer by layer spatial data that has been used in this research.

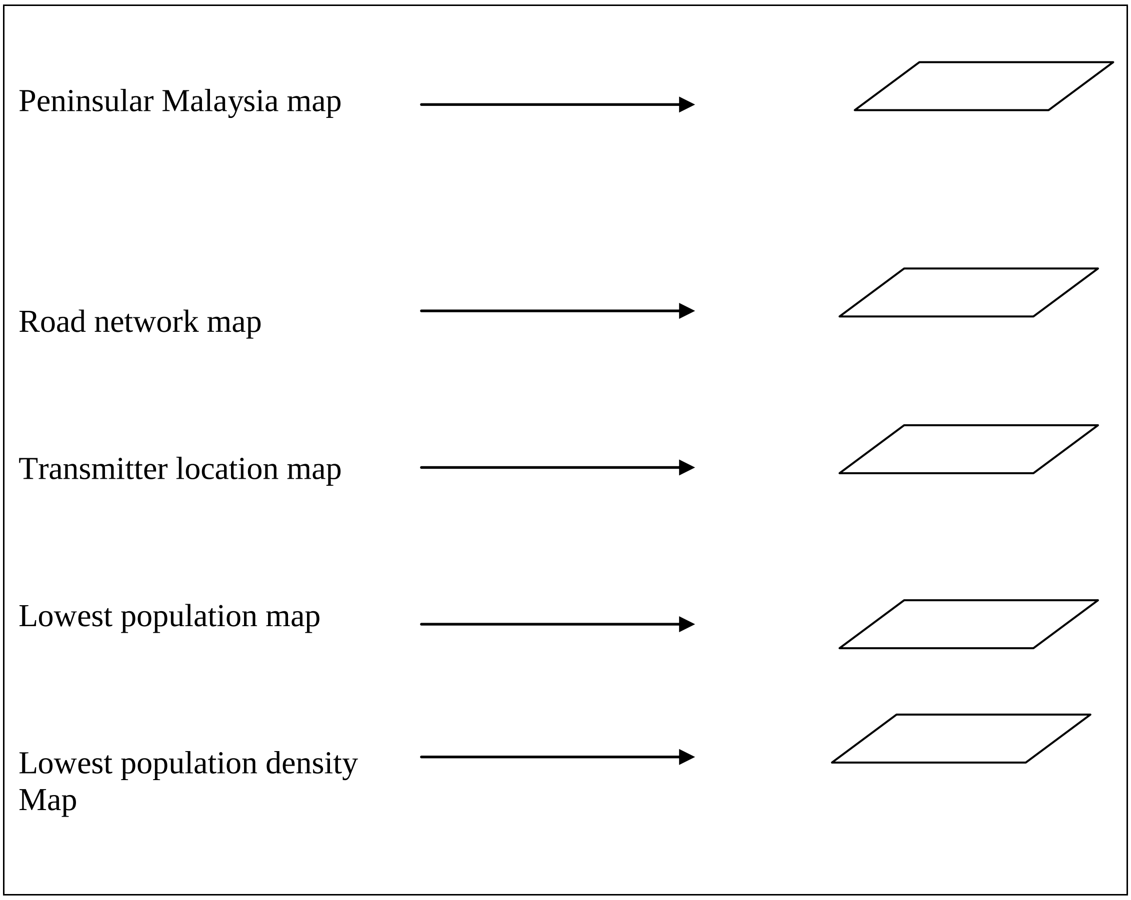


Figure 3.7: The layer by layer spatial data

Chapter 4

Methodology of RFI Observation

In this chapter, the methodologies of RFI observations in the candidate sites are presented. It covers how the detection was done, what was the material that was used and what were the procedures used to achieve the objectives. The observations have been done in three candidate sites in Peninsular Malaysia according to GIS analysis result. The candidates are Jelebu, Kg. Sekayu and Kg. Bertam. The same procedures were implemented in all candidate sites. Besides this, observation has also been done in reference sites to perform data comparisons. The reference sites that were selected was University of Malaya and the Meteorological station. It is located within Malaysia's capital city of Kuala Lumpur, hence a very high RFI level. It is also located on top of an exposed hill which is 109 m above sea level.

4.1 Description of the RFI Measurement System

Our RFI observations started with the setup of the equipments as illustrated in Figure 4.1. The spectrum analyzer that was used is capable of monitoring at frequencies of up to 2000 MHz with a 400 MHz span and resolution bandwidth (RBW) of approximately 180 kHz. Other than identifying the peaks and averaged signals, we also aim to monitor the fluctuations of these RFI signals with time. We measured the levels of RFI within this window and generally deduce whether there is any possible radio astronomical observation that can be done in any of the windows in the location chosen (see Tables 4.1). Low noise amplifier (LNA) was used to extend the sensitivity of the RF spectrum analyzer. The LNA has a 30 dB gain and 0.37 dB noise figure (NF). The very low lost coaxial cable (Belden 9913) with 50 ohm impedance was used. All the equipments and the characteristics are described briefly in Table 4.2.

Before scanning within this band, the signal levels must be recorded with and without the antenna and also with and without the LNA. This process was done to ensure that the signals receive were not generated by internal RFI. For each site, radio spectrum using a wide-band FM of up to 2 GHz was recorded every 3 hours until the 24-hours overall observation time was completed. The spectrums using narrow-band FM centered at 1420.4 MHz was monitored every 15 minutes within this 24-hours time frame in order to characterize the RFI fluctuations with time [34][35].

Table 4.1; Potential site coordinates

Location	Latitude	Longitude	Altitude(m)
Physics Department, University Malaya, Malaysia	03^{o} 07.396’ N	101^{o} 39.173’ E	78
Meteological Station	03^{o} 07.443’ N	101^{o} 39.445’ E	109
Jelebu	03^{o} 03.108’ N	102^{o} 03.912’ E	144
Sekayu	04^{o}57.967’ N	102^{o}57.332’ E	59
Bertam	05^{o}09.991’ N	102^{o}02.764’ E	87

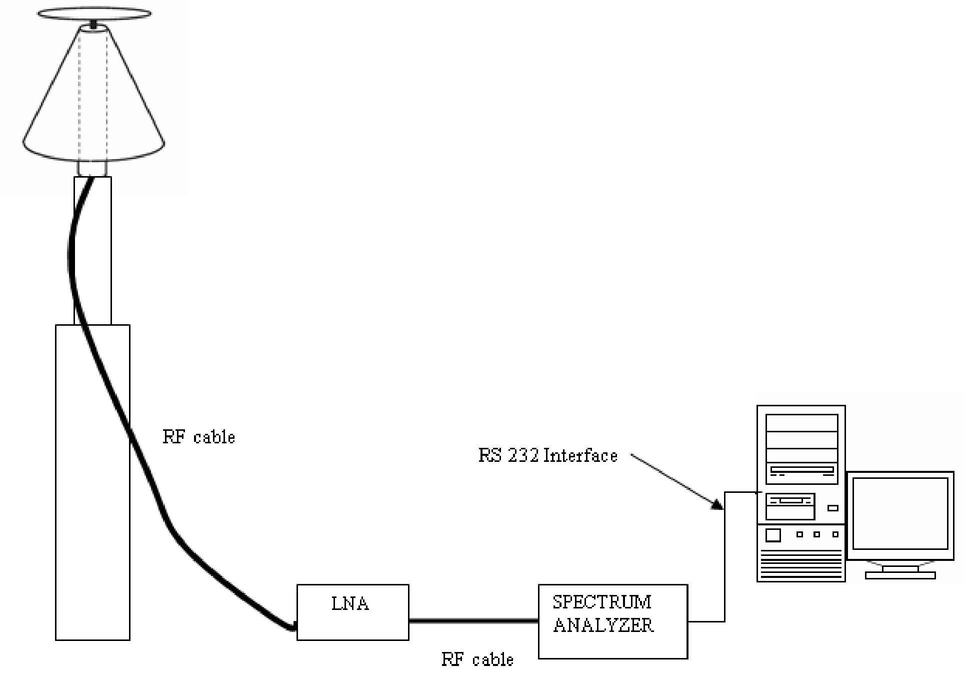


Figure 4.1: Block diagram showing the complete RFI Measurement System.

Table 4.2: Equipment lists and characteristics

Equipments	Characteristics
Antenna	Copper Discone (700 MHz-2000MHz)
RF Field Strength Analyzer 2.0 GHz (Protex 3200 Series)	Frequency range: 100KHz – 2060 MHz RBW : Wide FM - approx. 180 kHz Narrow - approx. 125 kHz AM/SSB - approx. 2.4 kHz
LNA	30 dB of gain and 0.37 dB of noise figure (NF)
Coaxial cable (50 ohm)	Belden 9913

4.2 Method and Measurements

This section below describes the procedure that was used to collect and process the data in every observation site. This section states the procedures and data analysis methods.

4.2.1 Description of RFI Measurements

The measurement data used in this experiment was collected by the spectrum analyzer using a discone antenna. The observations have been divided to two sections. First is the wideband observation at frequency 1-2000 MHz and the second is narrowband at frequency 1419 MHz-1421 MHz.

For the first step, the data was recorded every three hours until 24-hours overall observation time was completed. Each spectrum analyzer recorded data containing 161 data sets which means the 24-hour observation contains 1,288 data sets (8 x 161). For the second step, data will be saved every 15 minutes until 24-hours overall observation time was completed and will contain around 15,456 data sets.

4.3 RFI Measurements

The sensitivity of an observation in radio astronomy can be defined as the smallest changing power level ΔP in the power level P at the radiometer input. The sensitivity equation is: [36]

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{\Delta f_0 t}} \tag{4.1}$$

Where:

P and ΔP: power spectral density of the signal

Δf_0: bandwidth

t: integration time (assumed as 2000s)

P and ΔP in equation (1) can be expressed in temperature units through the Boltzmann's constant, k:

$$\Delta P = k\,\Delta T;\ \text{also } P = k\,T \tag{4.2}$$

Thus we may express the sensitivity equation as:

$$\Delta T = \frac{T_A + T_R}{\sqrt{\Delta f_0 t}} \tag{4.3}$$

Where:

T_A = Antenna noise temperature

T_R = Receiver noise temperature

Equations (1) or (3) can be used to estimate the sensitivities and interference levels for radio astronomical observations. An observing interference threshold level, ΔP_H is expressed as the interference power within the bandwidth, Δf that introduces an error of 10% in the measurement of ΔP (or ΔT) i.e:

$$\Delta P_H = 0.1 \Delta P \Delta f \tag{4.4}$$

Meanwhile the interference also can be expressed in term either in the total bandwidth or as *spectral*, S_H, per 1 Hz of bandwidth or *spectral flux density* dB($Wm^{-2}Hz^{-1}$). The values given are for an antenna having a gain, in the direction of arrival of the interference, equal to that of an isotropic discone antenna which has an effective area of:

$$A_e = 3\lambda^2 \frac{\sin^2\theta}{8\pi} = \frac{3\lambda^2}{8\pi}$$
$$(assumed \sin^2\theta = 1) \tag{4.5}$$

Values of $S_H\Delta f$ dB (Wm^{-2}) are derived from ΔP_H by adding:

$$20\log f - 95.54 \qquad \text{dB} \tag{4.6}$$

S_H is than derived by [15]

$$\Delta P_H + 30 + 20\log\left(f[MHz]\right) - 10\log\left(RBW\left(kHz\right)\right) - 95.54 \tag{4.7}$$

The value of -95.54 arises from conversion of various unit [15].

4.4 Description of the RFI Data Processing.

In this experiment, all measurement data sets, either wideband or narrowband was combined. This was done as follows:

Step one: The first data that contains two columns (frequency and dBm) was read and combined with all data sets according to time.

Step two: For the wide band, there are five recorded data sets in a 3-hour period of time. This is because of the limitation of our spectrum analyzer which can only record a maximum of 400 MHz in every recorded data. So, to reach the frequency of 2000 MHz, we need to record five data sets as one period of recorded data.

Step three: The RFI data processing is started by combining the five recorded data sets from 1 MHz to 2000 MHz. This step will be repeated in the next period of data recording until 24-hours. Eventually, the average of the 24-hours observation data was measured.

Step four: In the narrowband, the 15,456 data will be combined according to the time period from the first recorded data until ninety six recorded datas. The combination was arrayed by frequency. Lastly, the average of the 24-hour observation was measured.

Step five: Using the value in step three and four, the spectral flux density was calculated using Equation 4.7 above.

Step six: The graph spectral flux density versus frequency was plotted for wideband and narrowband. These graphs are shown in Chapter 5.

Chapter 5

Results and Discussions

Chapter 3 focused on laying out the theory of our research and data collection methodology, especially in the implementation of GIS for radio astronomy observations in selected sites in Peninsular Malaysia. We explained how GIS worked on the RFI selection site and what are the processes that are included in GIS analysis. This is followed by entering and discussing the relationship between spatial and attribute data.

In Chapter 4, the methodology for RFI observation for a potential site has been discussed. It includes the procedure of observation and how observation is performed. This is followed by the method to measure and analyze the data.

In this chapter we will present the result of GIS analysis that has been mentioned in Chapter 3. It includes the maps of each parameter that is produced by the GIS software and the parameter overlay map for analysis. After that we will present the RFI observation data in two methods, wideband and narrowband. The wideband analysis was used to show the RFI strength in a potential site at the frequency of 1 MHz until 2000 MHz. Meanwhile, the narrowband analysis was to focus the RFI signal at the Hydrogen line frequency (1420.4MHz).

5.1 GIS Results

The RFI site selection in Peninsular Malaysia involves the collection of geographical data related to various aspects. The on screen digitizing capabilities of ArcGIS 9.3 software was used to convert the scanned maps to vector format for further analysis. The various thematic maps of the Peninsular Malaysia prepared by ArcGIS 9.3 will be created as state boundary maps at Peninsular Malaysia, road Network map, transmitter location map, lowest population site in Peninsular Malaysia map, lowest population density site in Peninsular Malaysia, and highland site in Peninsular Malaysia.

The various thematic maps of the Peninsular Malaysia prepared by GIS are given below:

a) State boundaries maps at Peninsular Malaysia (see Figure 5.1)

b) Main road network map (see Figure 5.2)

c) Transmitter location map (see Figure 5.3)

d) Lowest population site in Peninsular Malaysia map (see Figure 5.4)

e) Lowest population density site in Peninsular Malaysia (see Figure 5.5)

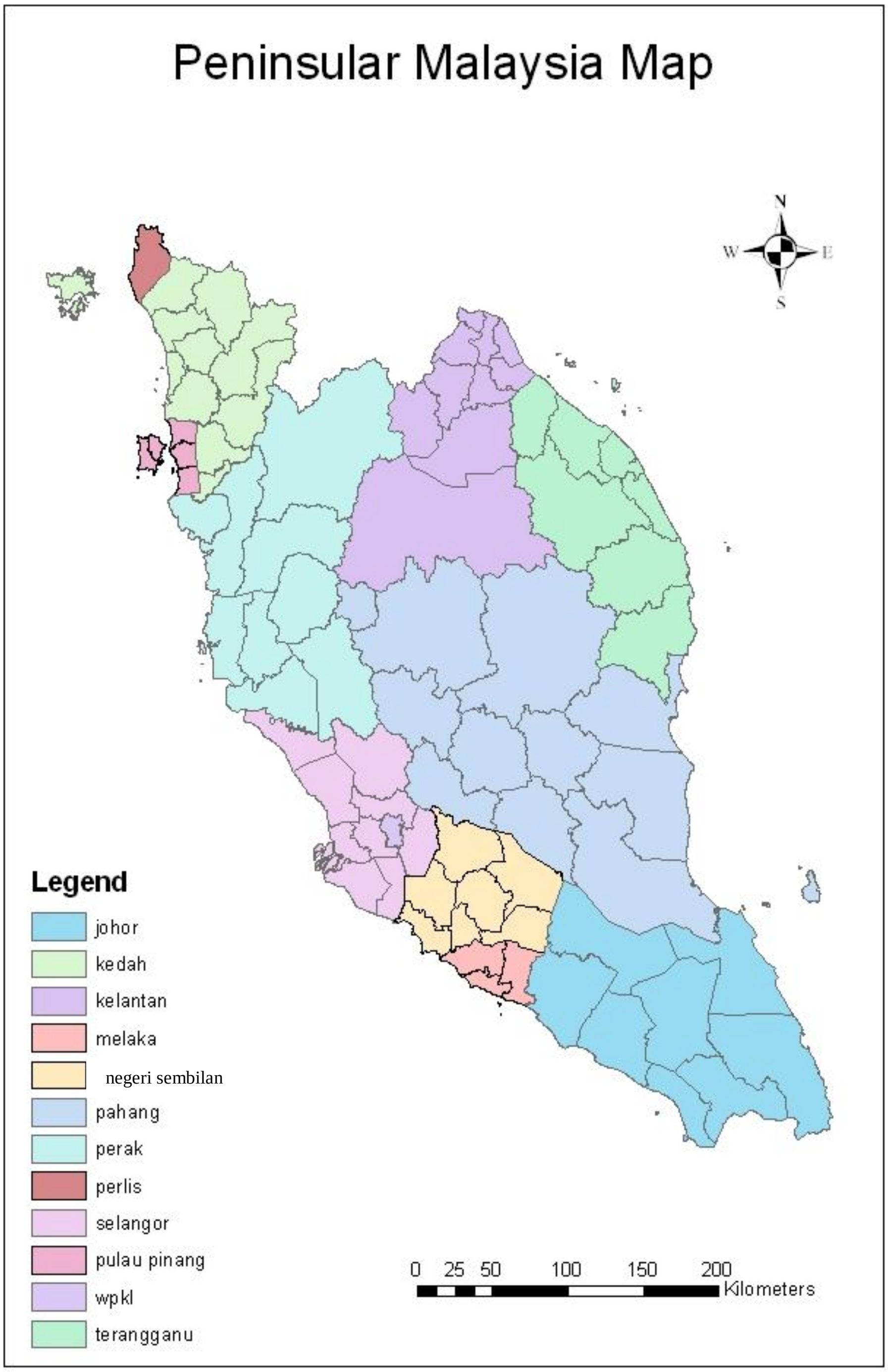


Figure 5.1: State boundaries map in Peninsular Malaysia

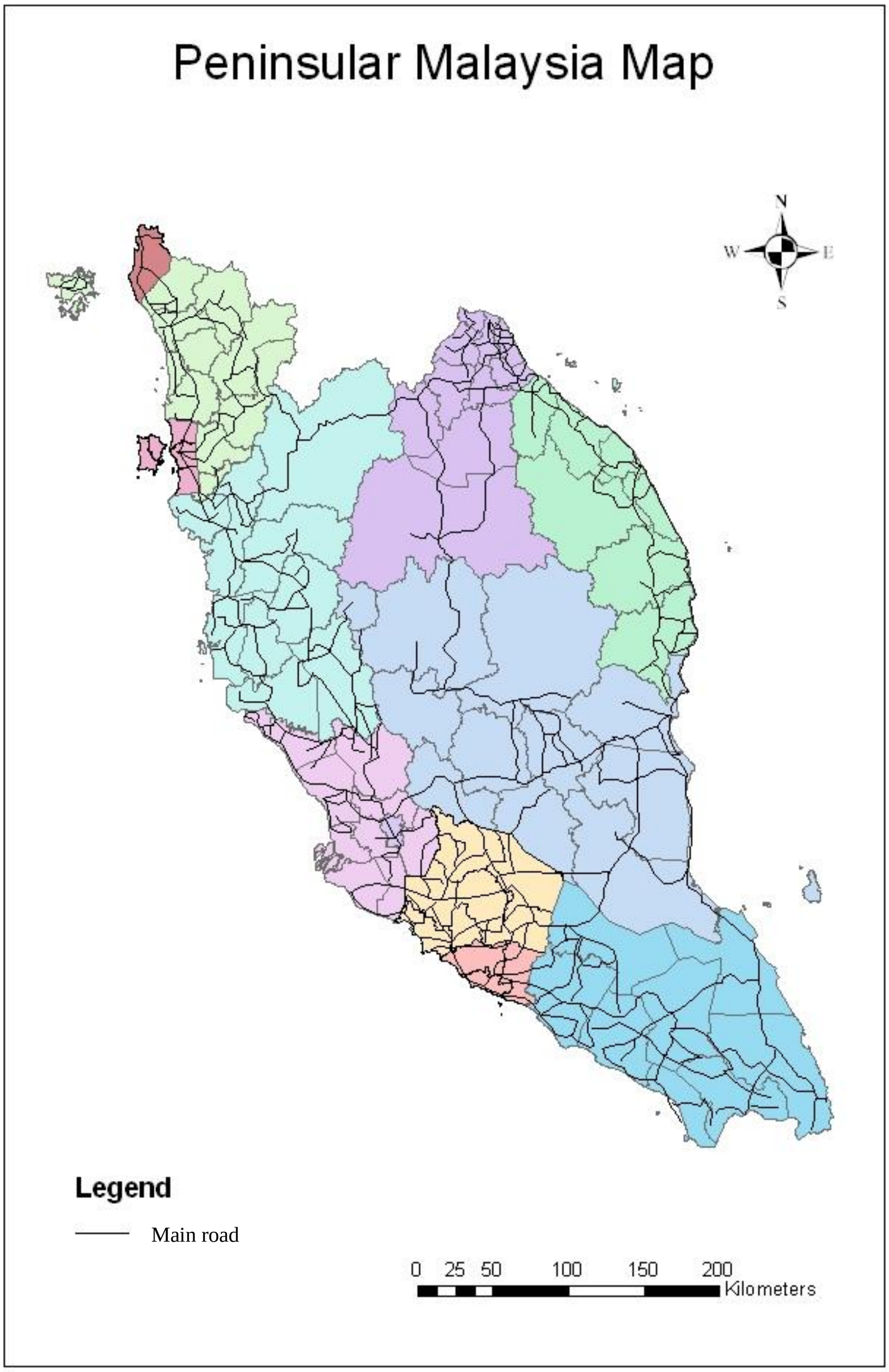


Figure 5.2: Road Network map in Peninsular Malaysia

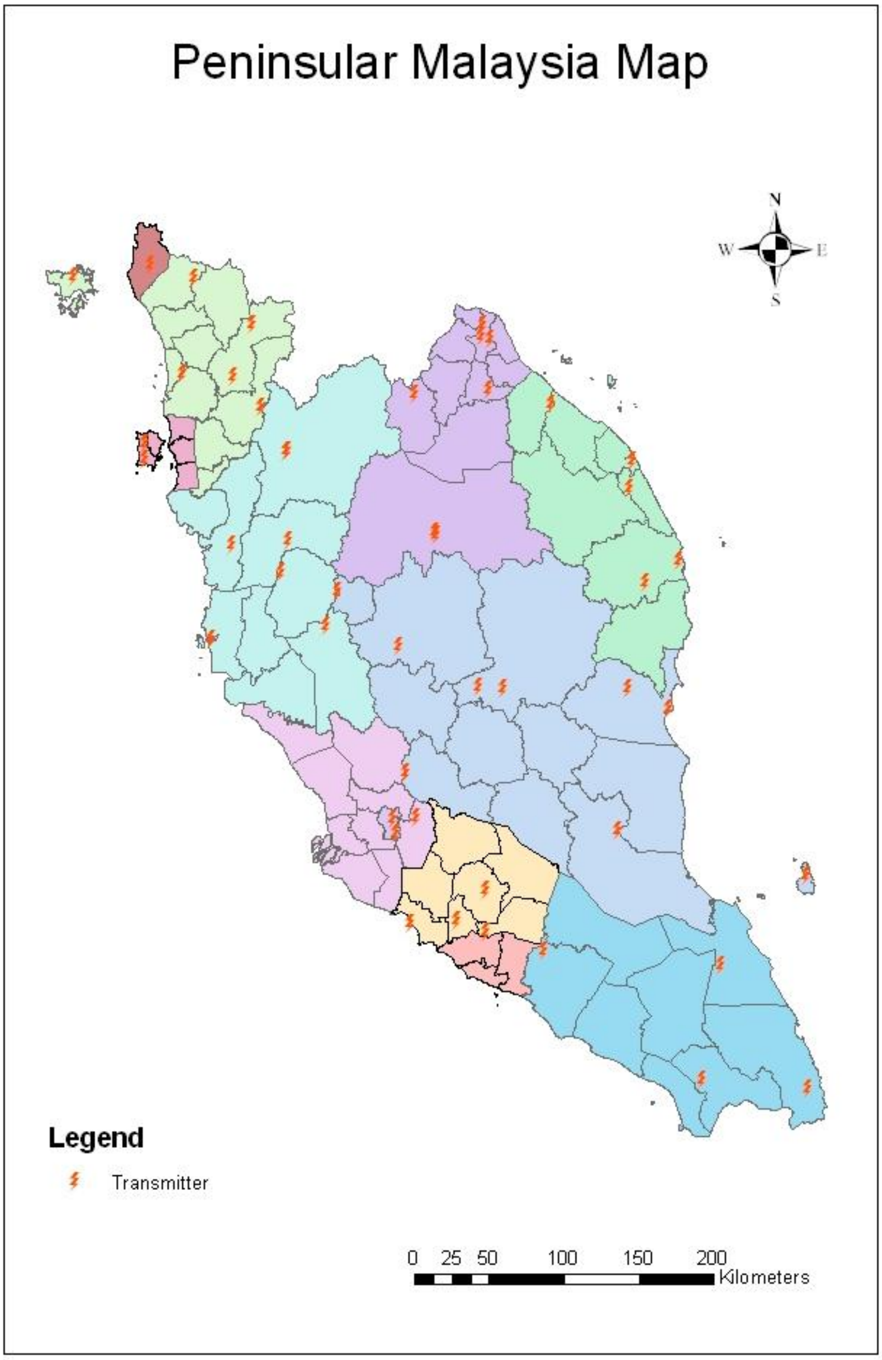


Figure 5.3: Transmitter location in Peninsular Malaysia map

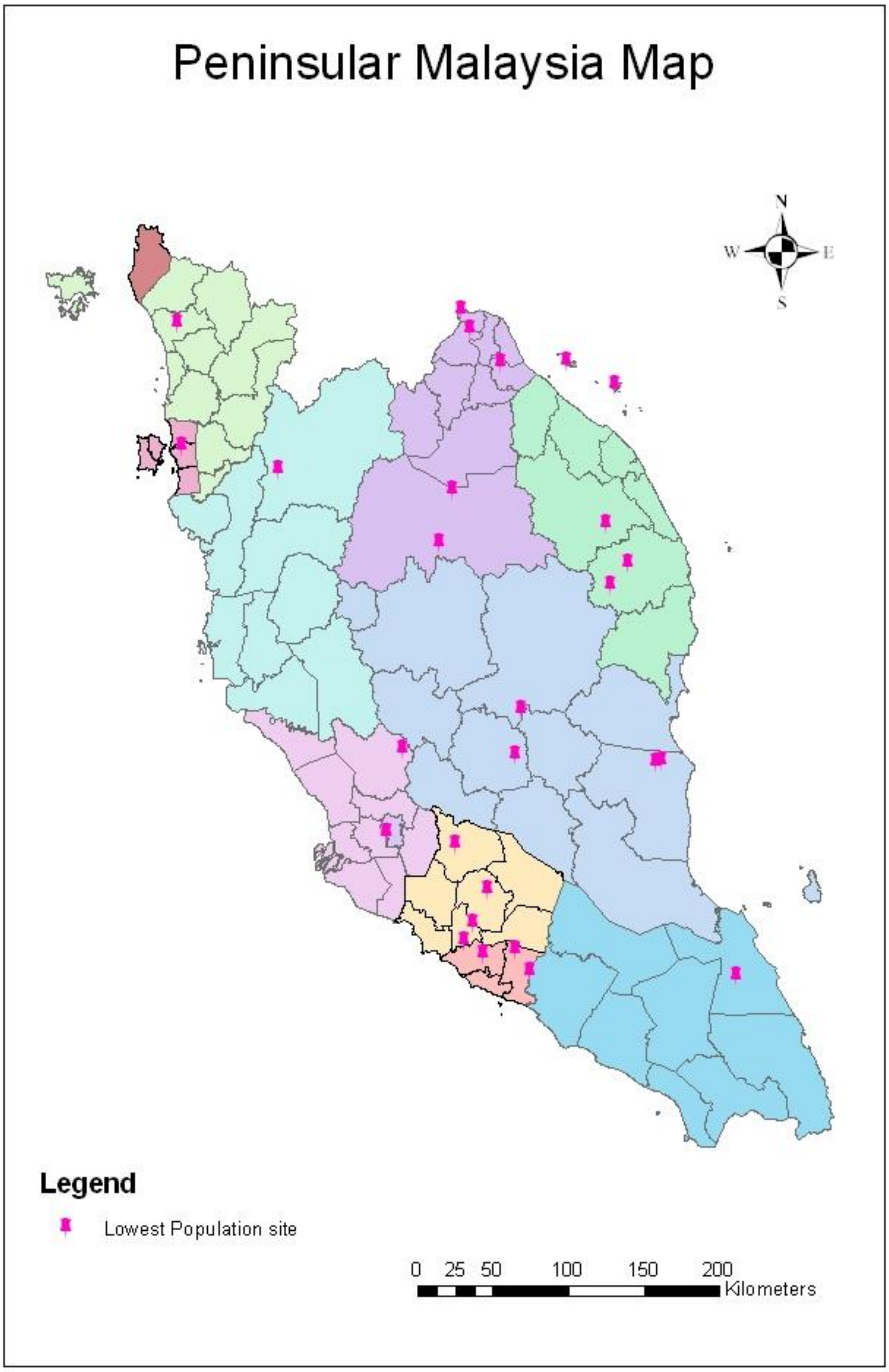


Figure 5.4: Lowest population site in peninsular Malaysia map (see Appendix E)

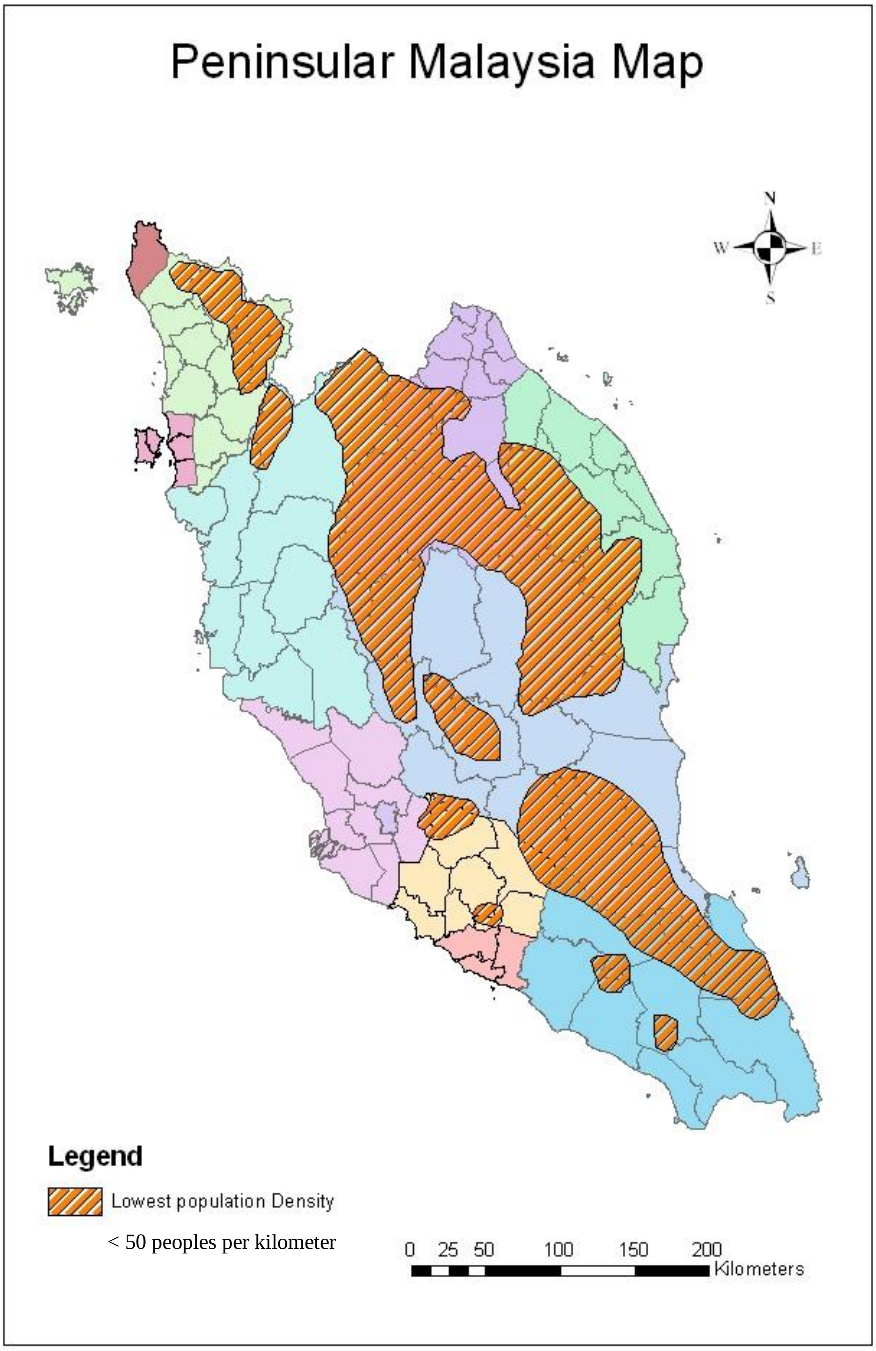


Figure 5.5: Lowest population density site in Peninsular Malaysia (see Appendix F)

We planned to select radio astronomy observation locations in a priority manner. By adopting different parameters, three criteria levels (level I, II, and III) of priorities have been chosen for selecting the radio astronomy site locations. The spatial model has been developed by implementing these criteria and related conditions under GIS environment. In general, various criteria adopted for selecting the sites using GIS include:

1) Site should be far from human activities

2) Site should be at low population densities

3) Site should have adequate road accessibility

4) Site should not be within 20 km radius from the transmitter signals.

The potential site for each parameter was created. Finally, the parameters that contribute to the RFI level were applied to find a suitable site for radio astronomical observation in Peninsular Malaysia. A spatial model has been developed to select three best locations of radio astronomy observation sites. The spatial models have been developed to implement these conditions using GIS.

5.2 Analysis of GIS Results

When all the layers are combined and a 20km buffer zone is given to the transmitter, a few suitable sites for radio astronomical observation candidates site will be get (see Figure 5.5). From the results, it shows two candidate sites that fulfill the parameters. The first candidate site is Kg Sekayu (latitude: $04^{o}57.967'$ N, longitude: $102^{o}57.332'$ E) in Terengganu. This site is listed with sites with lowest population and lowest population density. Meanwhile this site is excluded from the transmitter signals and earth surfaces like craters which can be a shield from the RFI in surroundings (see Appendix F). This site has good road accessibility, which we give a priority level I to this site. The second site is Kg Bertam (latitude: $05^{o}09.991'$ N, Longitude: $102^{o}02.764'$ E). This site is also included in sites with lowest population and has lowest population density. This site is also not covered by the signal from transmitter and having moderate rail accessibility. We give the priority level II to this site.

The last site we choose to give priority level III is Jelebu (latitude: 03^{o} 03.108' N, longitude: 102^{o} 03.912' E). This site is not included as a lowest population site but is considered a lowest population density site. This site is the driest site in Peninsular Malaysia. This site is also not covered by transmitter signals.

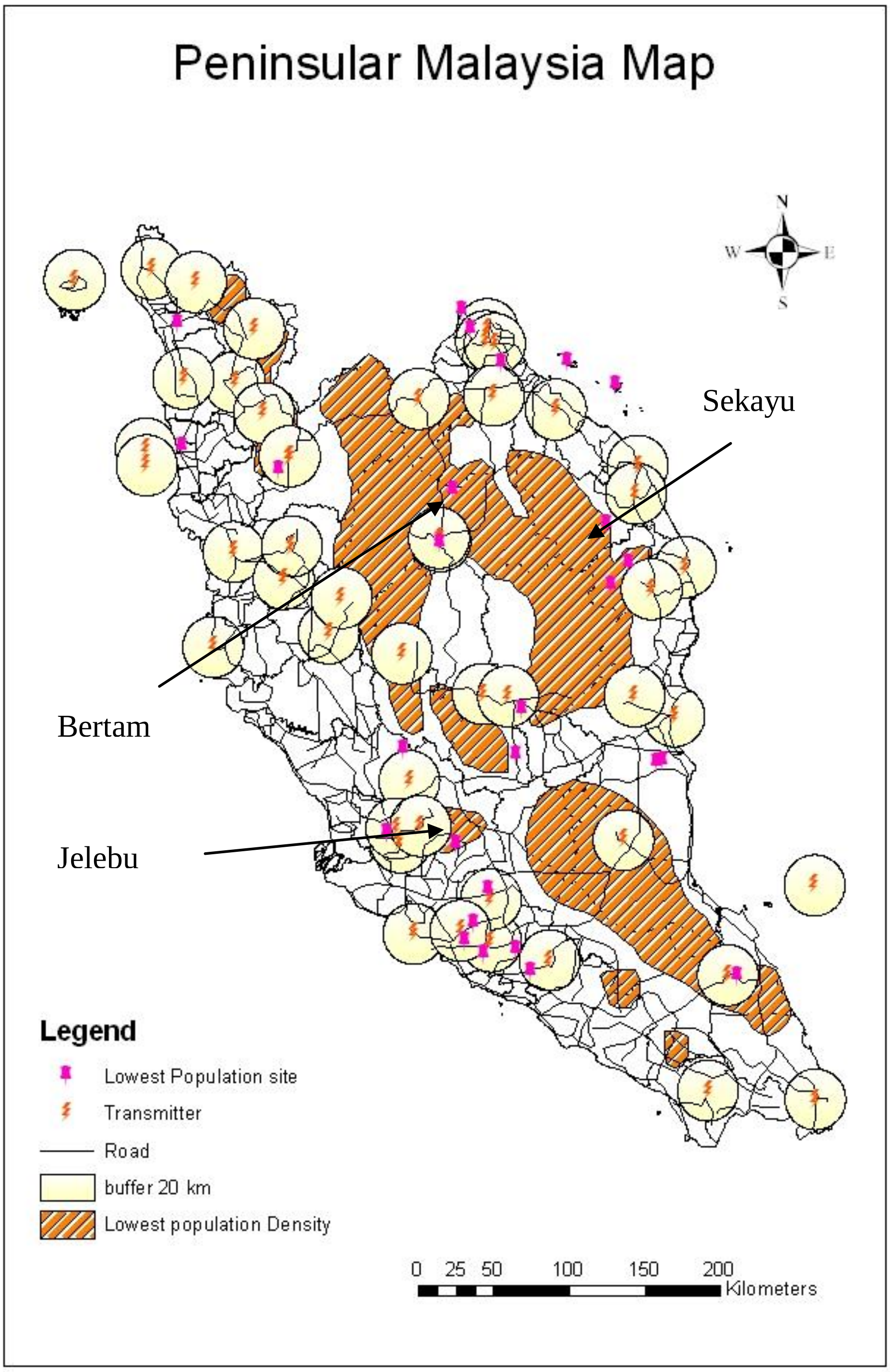


Figure 5.6: Candidate sites for radio astronomical observation in Peninsular Malaysia map.

5.3 RFI Results

After recognizing potential sites, we traveled to the sites to measure the actual strength of RFI. Before that, we have done observations in our two reference sites. The first site we chose as a reference site was in University of Malaya. The site was considered to have high RFI. This is because we need to make a comparison between the RFI of the sites in the end of the research. The second site we chose as a reference site is in the Meteorological Station. The site is located in the high altitudes (109m). This is because we want to investigate if altitude affects the RFI observation data. It was found that in radio frequency metrology the electromagnetic and power levels (dBm) are usually used as key indicators of signal strength. However, in this research we chose to use *spectral flux density* (dBW/m^2Hz^{-1}) that was been discussed in Chapter 4.3, Equation 4.7. This is because that unit shows the density per unit frequency [15]. This is significant as it shows the density of power at each frequency.The RFI result for wideband and narrowband is shown below.

5.3.1 Wideband

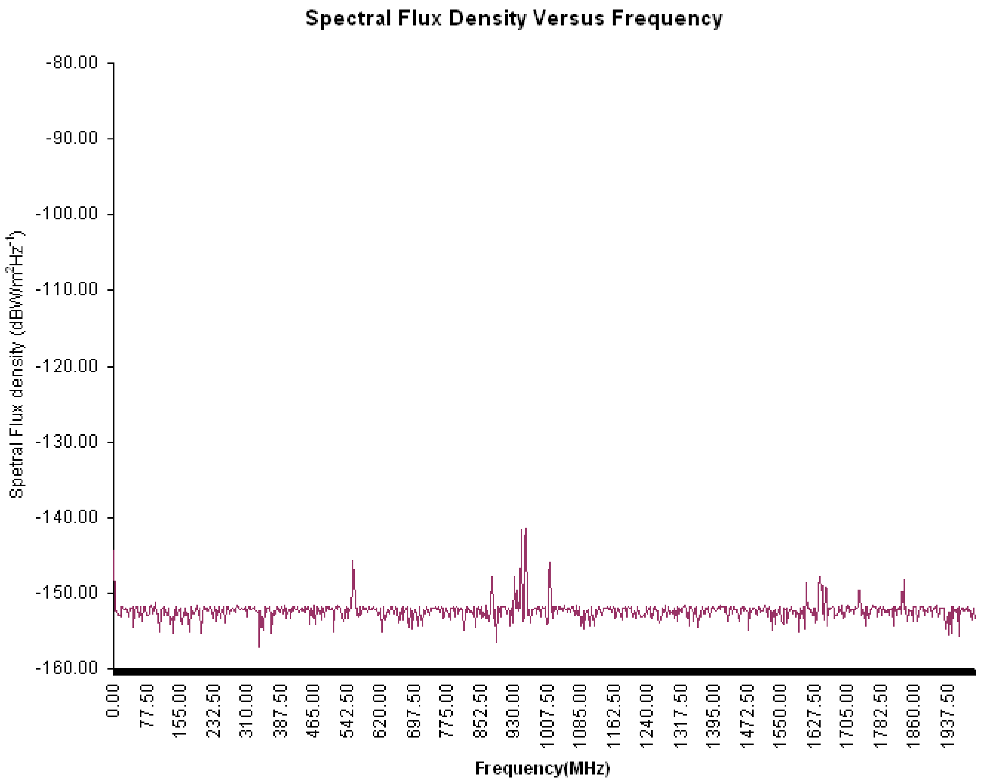


Figure 5.7: The RFI result in Sekayu (Potential site)

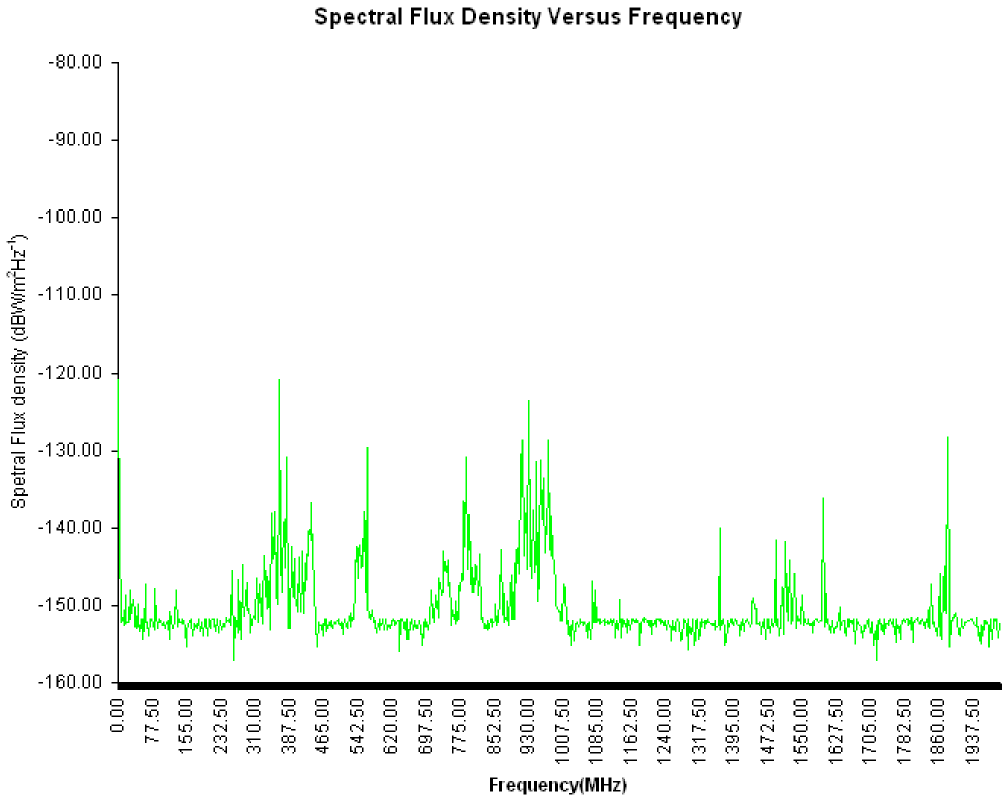


Figure 5.8: The RFI result in Bertam (Potential site)

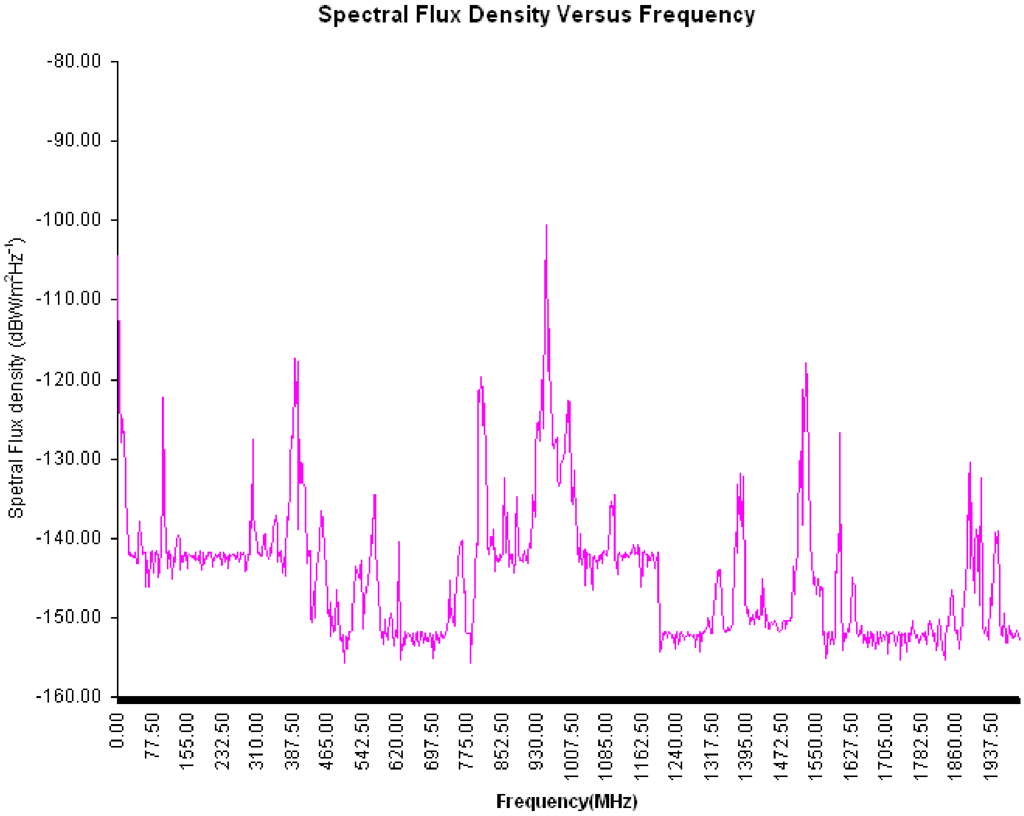


Figure 5.9: The RFI result in Jelebu (Potential site)

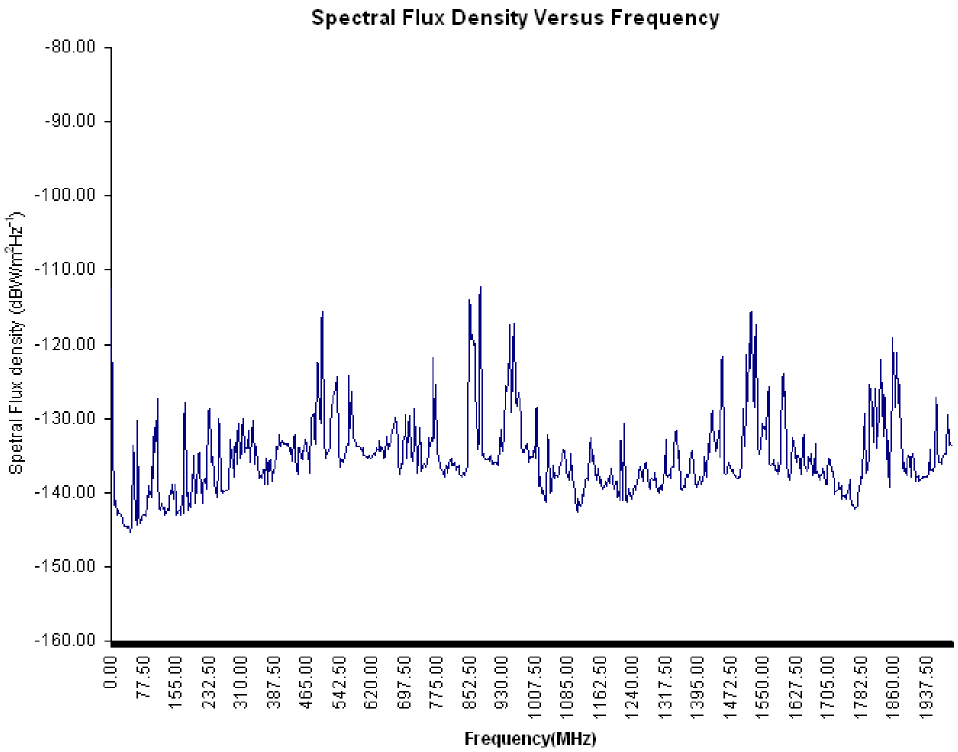


Figure 5.10: The RFI result in Meteorological Station (reference site)

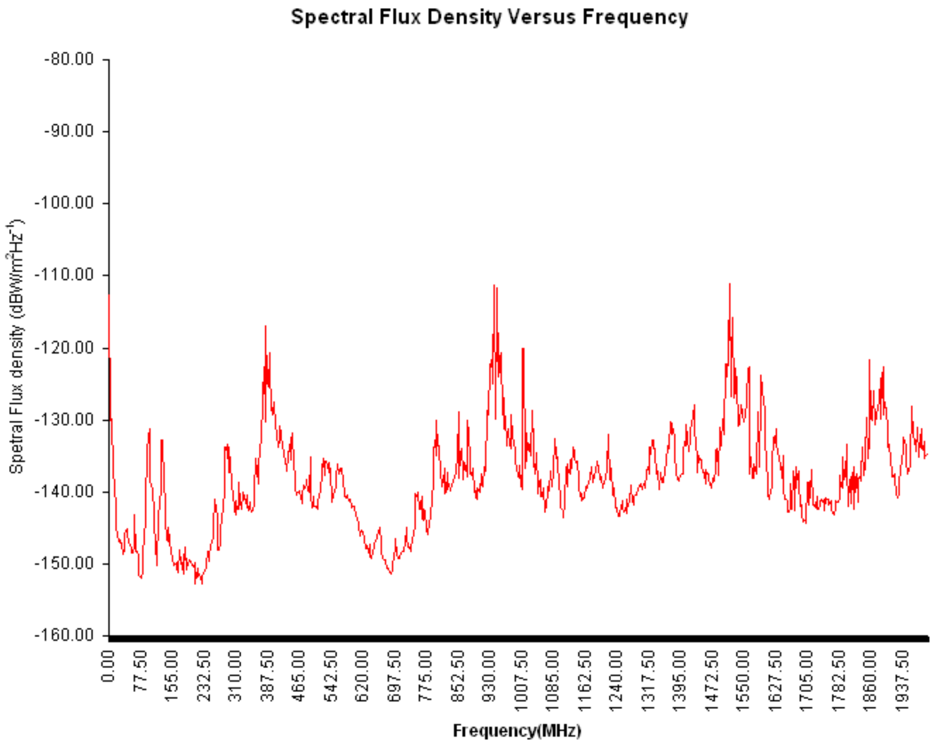


Figure 5.11: The RFI result in Physics Department, University Malaya (reference site)

5.3.2 The Wideband's Result Analysis

The results show the signals from the chosen prime potential sites. According to the results, the lowest RFI among the candidate sites is at Sekayu with an average signal -152.32 $dBWm^{-2}Hz^{-1}$ (see Figure 5.7). The lack of RFI is also obvious around this site as it is located in the middle of a forest reserve land. There are only several signals appearing at that site such as from broadcasting at frequency 542-543 MHz, telecommunication at frequency 920-940 MHz and satellite at frequency 1600-1650 MHz. This is a true phenomenon that we observed from that site and so far there is no RFI research that has been done in Sekayu for comparison. This situation indicated Sekayu has the lowest level of RFI if compared to the other sites.

The second best is Bertam (see Figure 5.8). This is followed by Jelebu (see Figure 5.9). The University of Malaya Meteorological Station (see Figure 5.10) with average signals -135.13 $dBWm^{-2}Hz^{-1}$, appears to be the worst of the 5 sites from existing RFI measurements. It is located within Malaysia's capital city of Kuala Lumpur, and located on top of an exposed hill which is 109m above sea level. That site has the potential for an increasing risk of RFI from broadcasting signals, telecommunication signal, satellite signals and gradual expansion of sources of RFI from people and buildings. This is also comparable to the RFI levels observed at the University of Malaya Physics Department (see Figure 5.11). Both sites are covered by strong RFI. The distance from each other is just 500m.

The trends of the signals are very high if the strength of the RFI sources is high. For example, in Physics Department, the highest RFI measured is at frequency 900-1007 MHz which is from telecommunication services. We suspect that the RFI is from Telekom Malaysia signals because there is a transmitter on top of the Telekom Malaysia tower that is located 500m from our observation site. However, if the strength from the RFI sources is low, the trend of the signal is very low and becomes straight level. The straight level in each graph indicates there are no signals detected in their particular frequency. A possibility that might be happening is the signal is too weak and is lower than our spectrum analyzer's noise level floor which is -155 $dBWm^{-2}Hz^{-1}$. The detail about the sources of signal in whole sites in a particular frequency can be seen in Appendix G.

Figure 5.12 below shows the comparison made between all the chosen sites. From the RFI spectra results, we can conclude that the 3 potential sites are relatively free of strong RFI. They are Sekayu, Bertam and Jelebu. The RFI spectra of the two

University Malaya's sites are considered very bad but it is useful for comparison purposes. Main telecommunication and navigation RFI are from Celcom at frequency 945 MHz and satellite navigation at frequency 1515 MHz. The features of sites that need to be avoided to pin-point a good site to setup radio astronomical telescopes are population density, transmitter location, land contour and road networks which have been discussed in Chapter 3.

We stress that the best site has to be nearby or within the premises of an institution which we can do collaborative work with. It is very difficult to build a radio telescope in a secluded and isolated area as the lack of basic setup and living infrastructure can cause a huge problem. We found that the 1420.4 MHz frequency is not entirely free from RFI but further studies are needed. The entire results can be concluded in the Table 5.12 below.

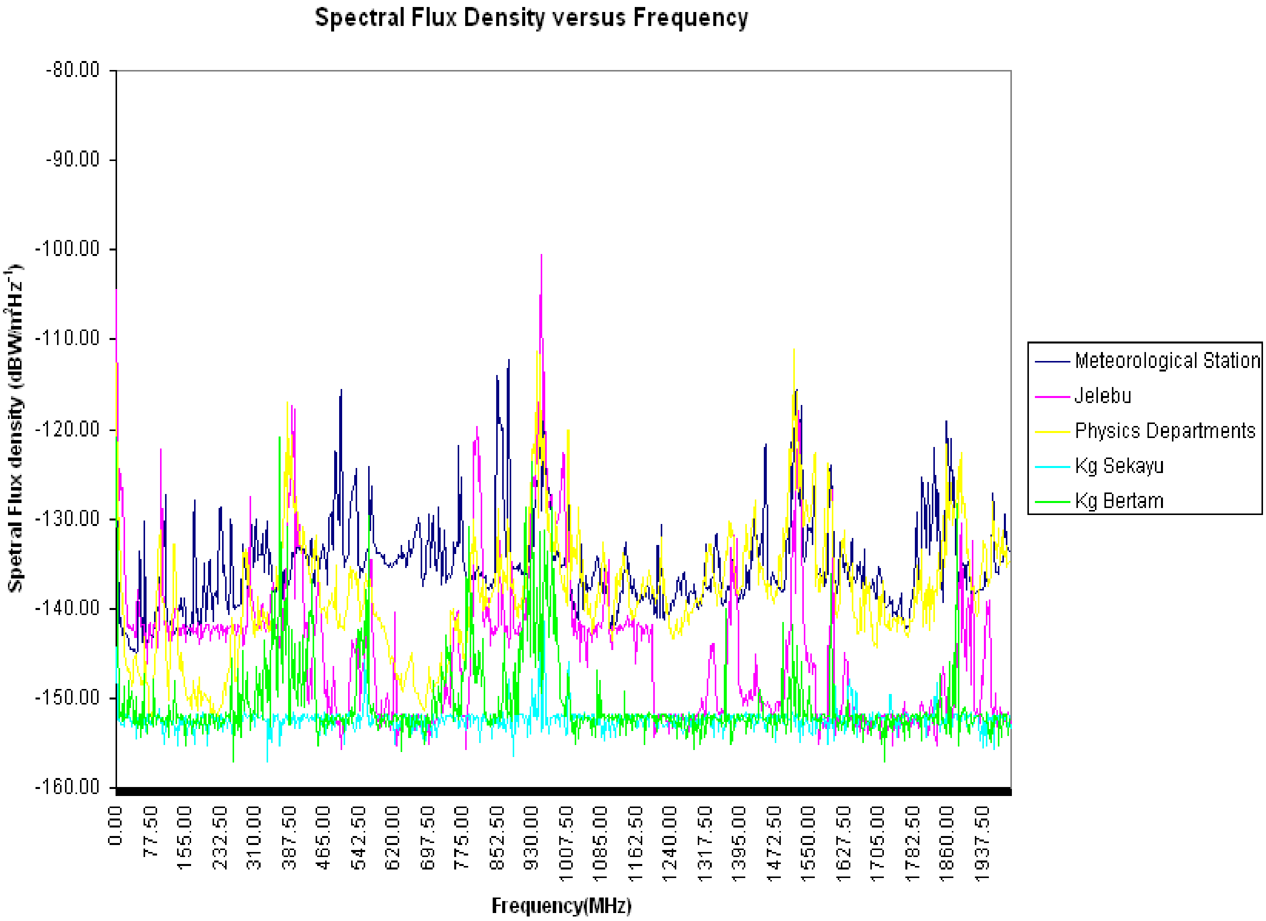


Figure 5.12: The wideband RFI results from the entire sites

Table 5.1: The wideband RFI results from the entire sites. (Error are obtained from standard deviation of collected data)

		Physics Department.	Meteorological Station	Jelebu	Sekayu	Bertam
Highest 3 peaks (± 1.64 *dBWm^{-2}Hz^{-1}*)	1	-111.07 (1515 MHz)	-112.32 (877.5 MHz)	-100.57 (950MHz)	-141.37 (947.5 MHz)	-120.90 (364 MHz)
	2	-111.23 (940 MHz)	-114.07 (850 MHz)	-107.87 (945 MHz)	-142.96 (955 MHz)	-123.65 (930 MHz)
	3	-111.73 (947.5 MHz)	-114.50 (875 MHz)	-109.37 (947.5 MHz)	-143.35 (945 MHz)	-128.83 (1880 MHz)
Average signals (±5.96 *dBWm^{-2}Hz^{-1}*)		-138.36	-135.13	-144.63	-152.32	-150.55

5.3.3 Narrowband

The graph below shows the result from 24 hours narrowband observation in all locations. It is followed by the signal fluctuations for the 1420.4 MHz Hydrogen Line spectrum.

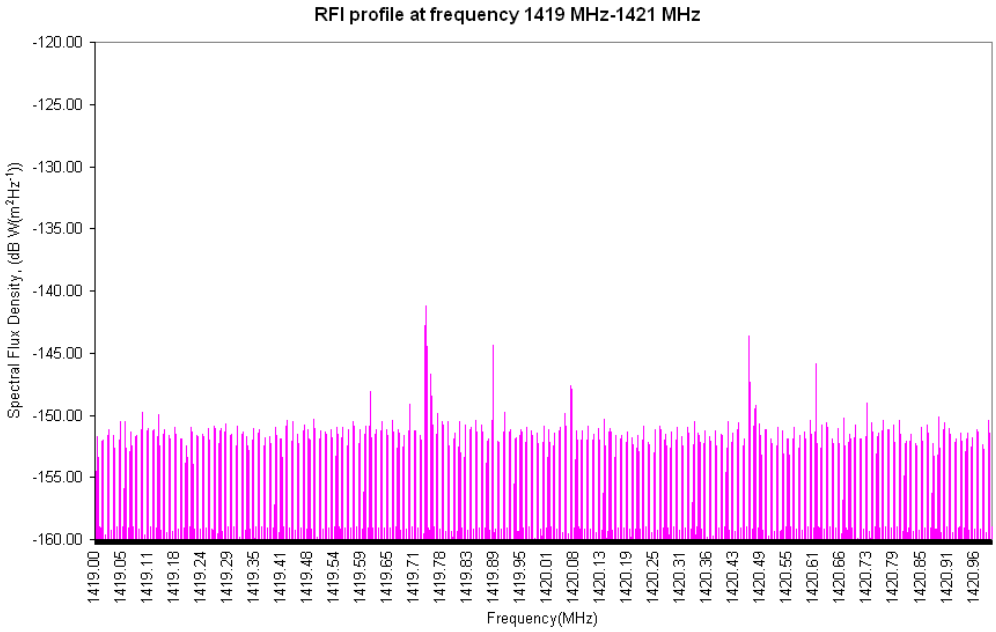


Figure 5.13: The RFI result in Physics Department, University Malaya (reference site)

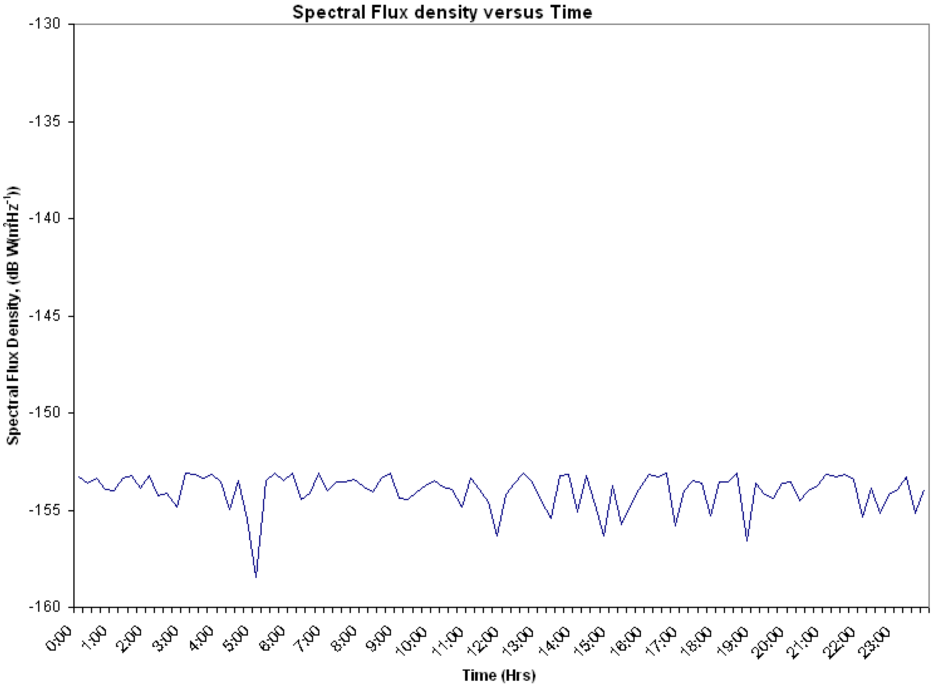


Figure 5.14: The signal fluctuation result at frequency 1420.4 MHz in Physics Department, University Malaya (reference site)

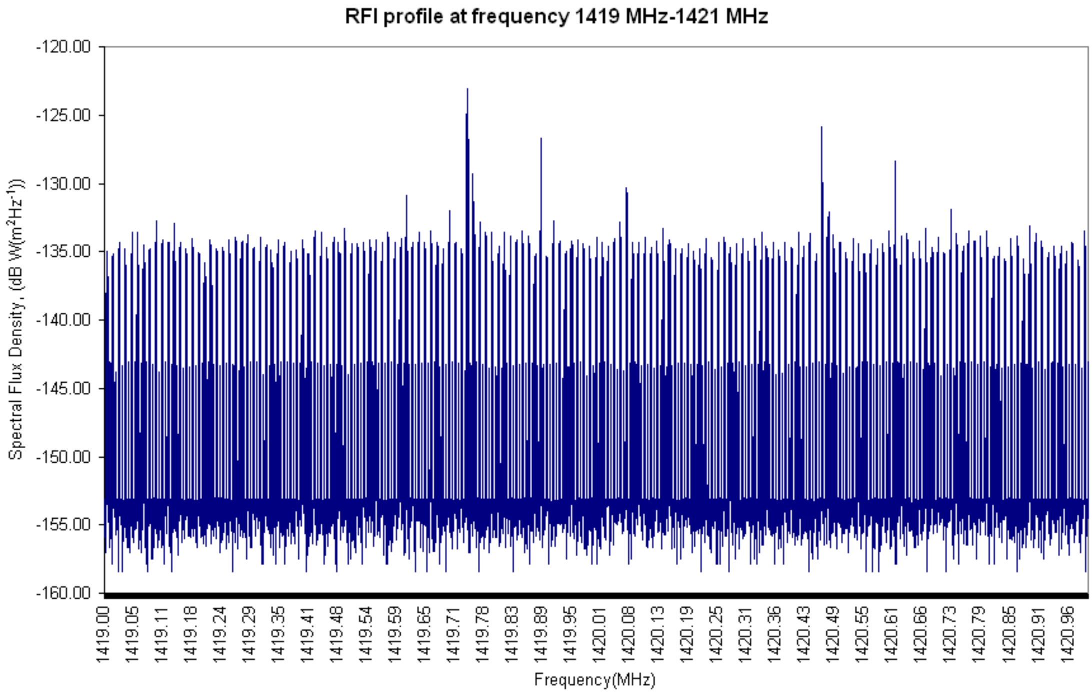


Figure 5.15: The RFI result in Meteorological Station (reference site)

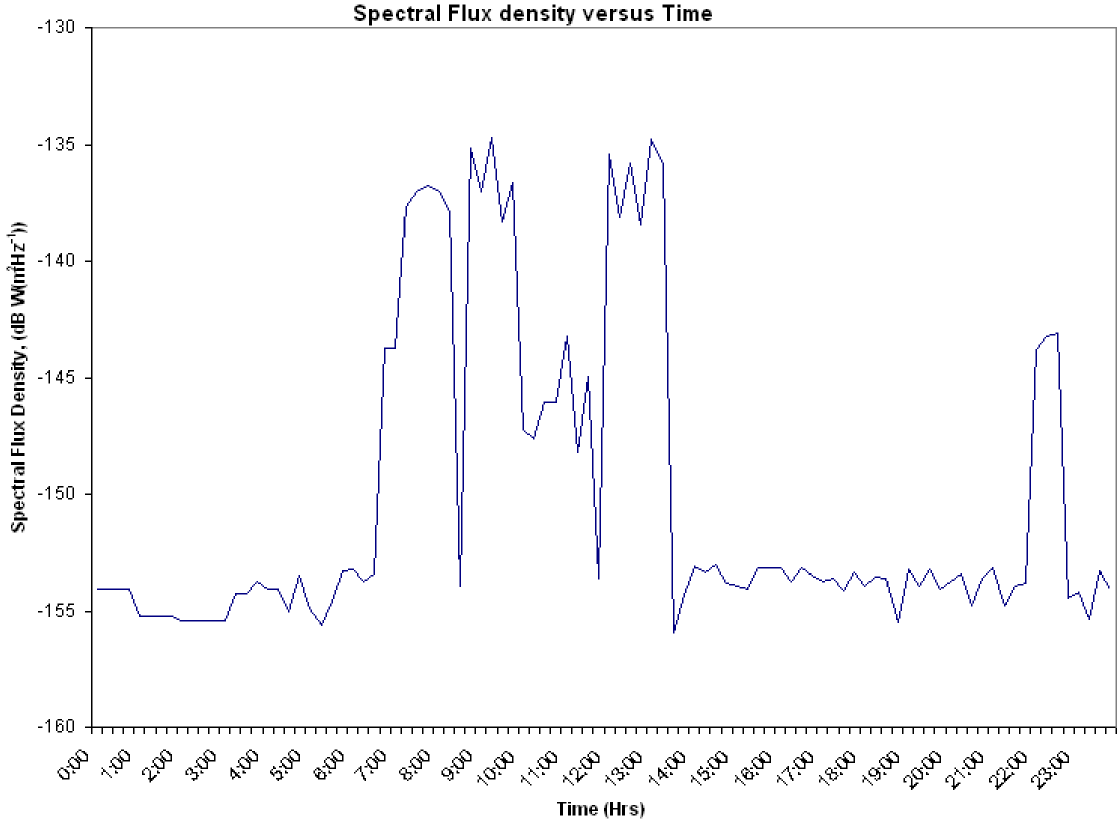


Figure 5.16: The signal fluctuation result at frequency 1420.4 MHz in Meteorological Station (reference site)

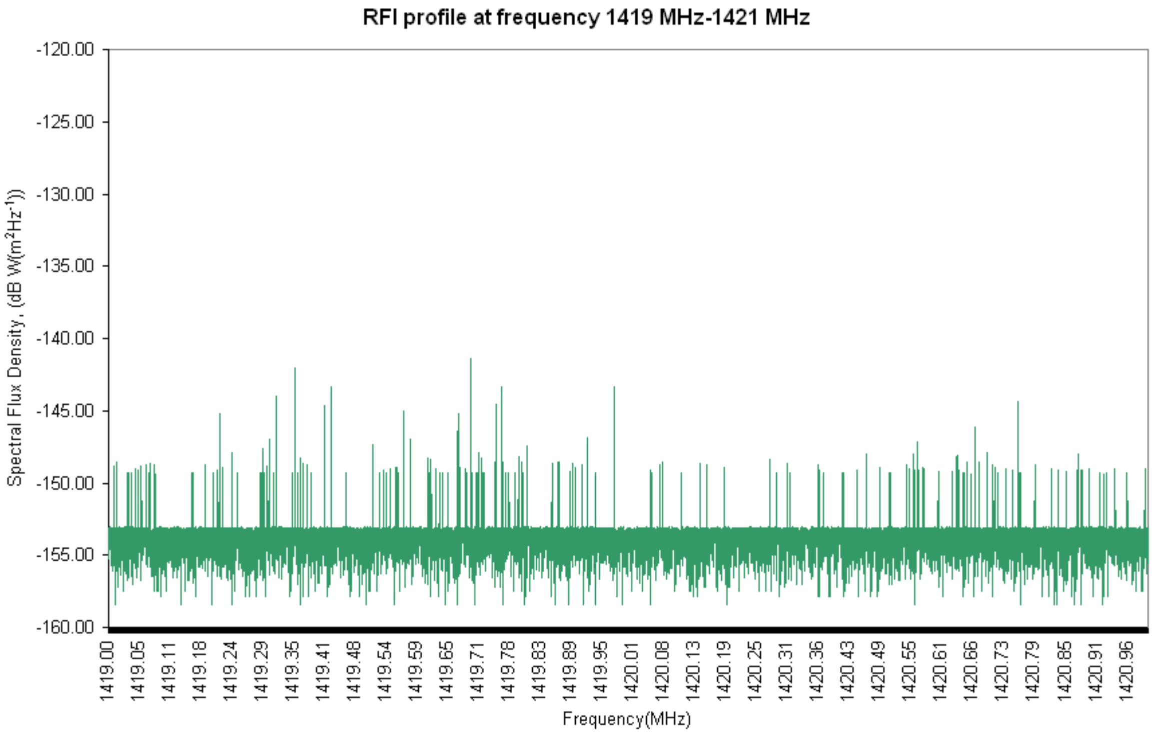


Figure 5.17: The RFI result in Jelebu (Potential site)

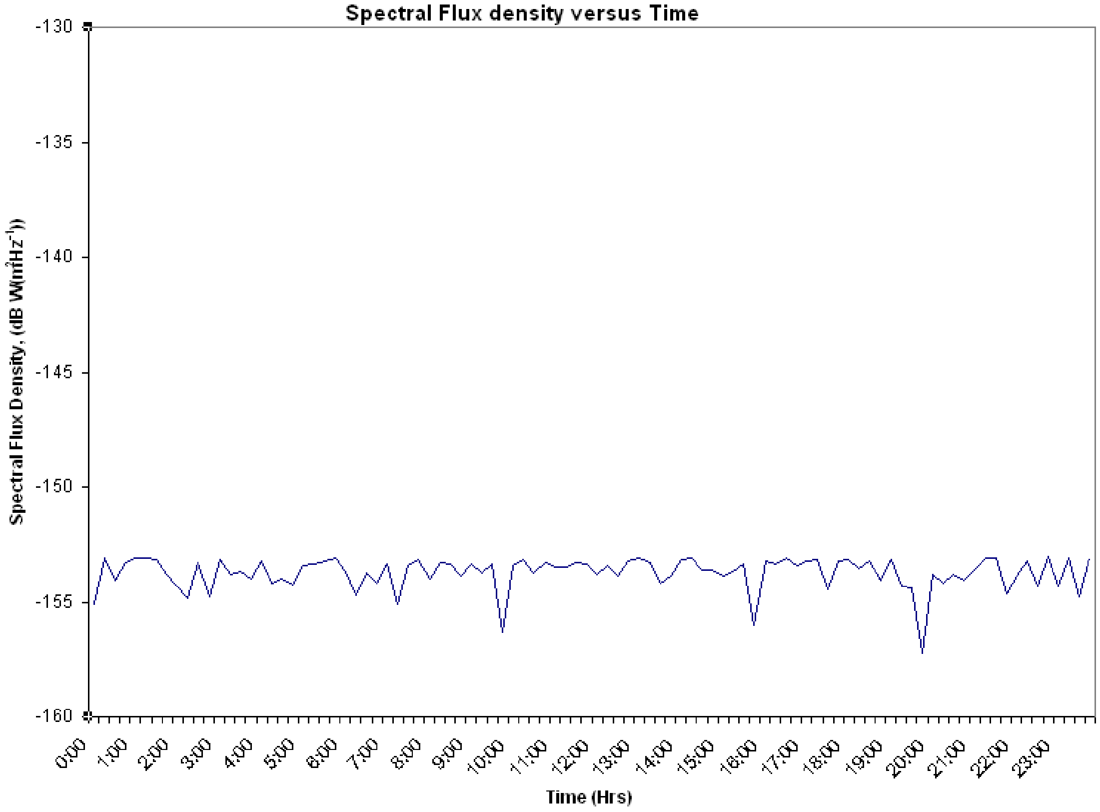


Figure 5.18: The signal fluctuation result at frequency 1420.4 MHz in Jelebu (Potential site)

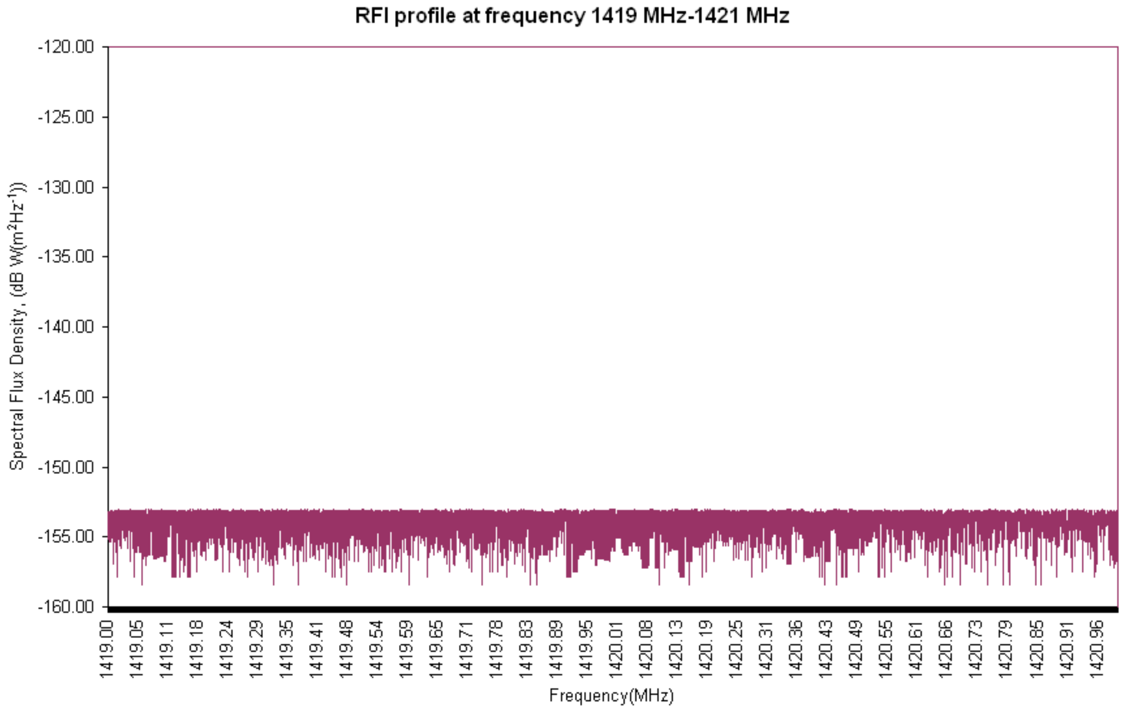


Figure 5.19: The RFI result in Bertam (Potential site)

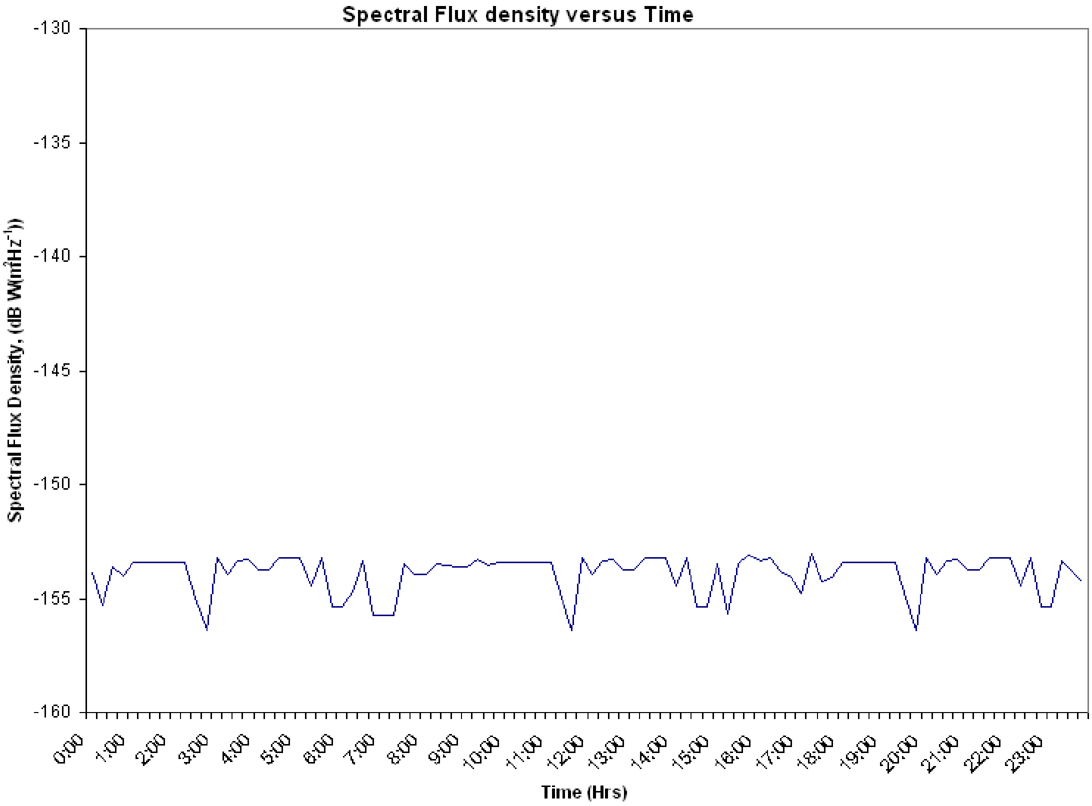


Figure 5.20: The signal fluctuation result at frequency 1420.4 MHz in Bertam (Potential site)

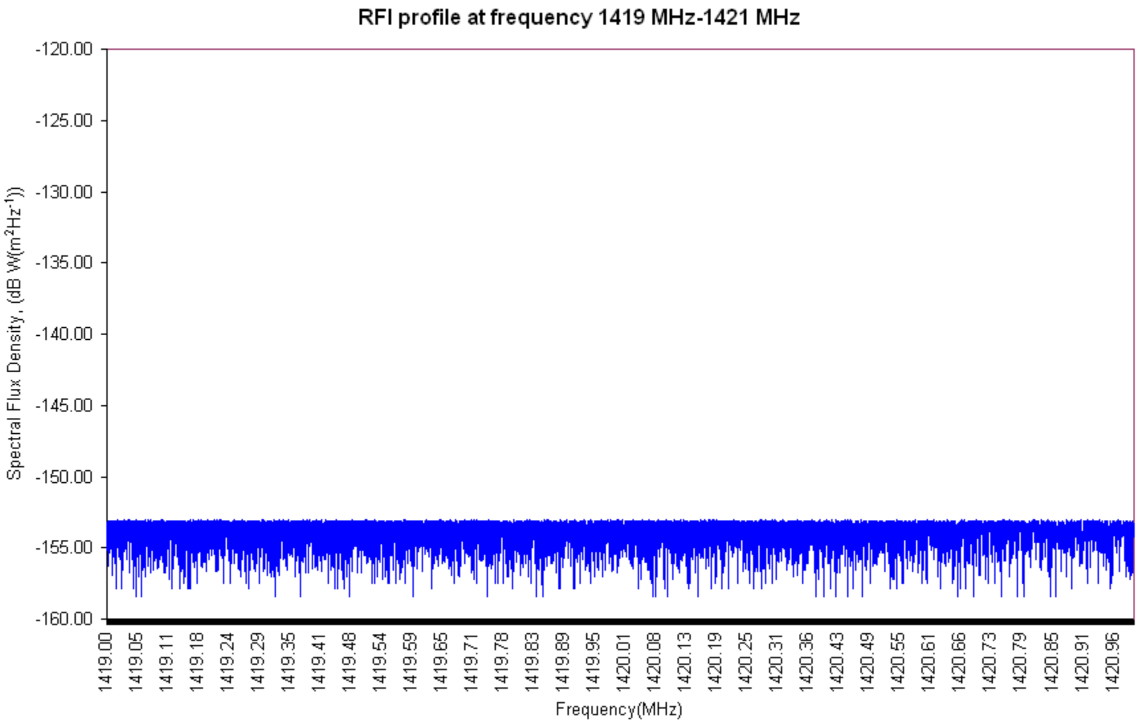


Figure 5.21: The RFI result in Sekayu (Potential site)

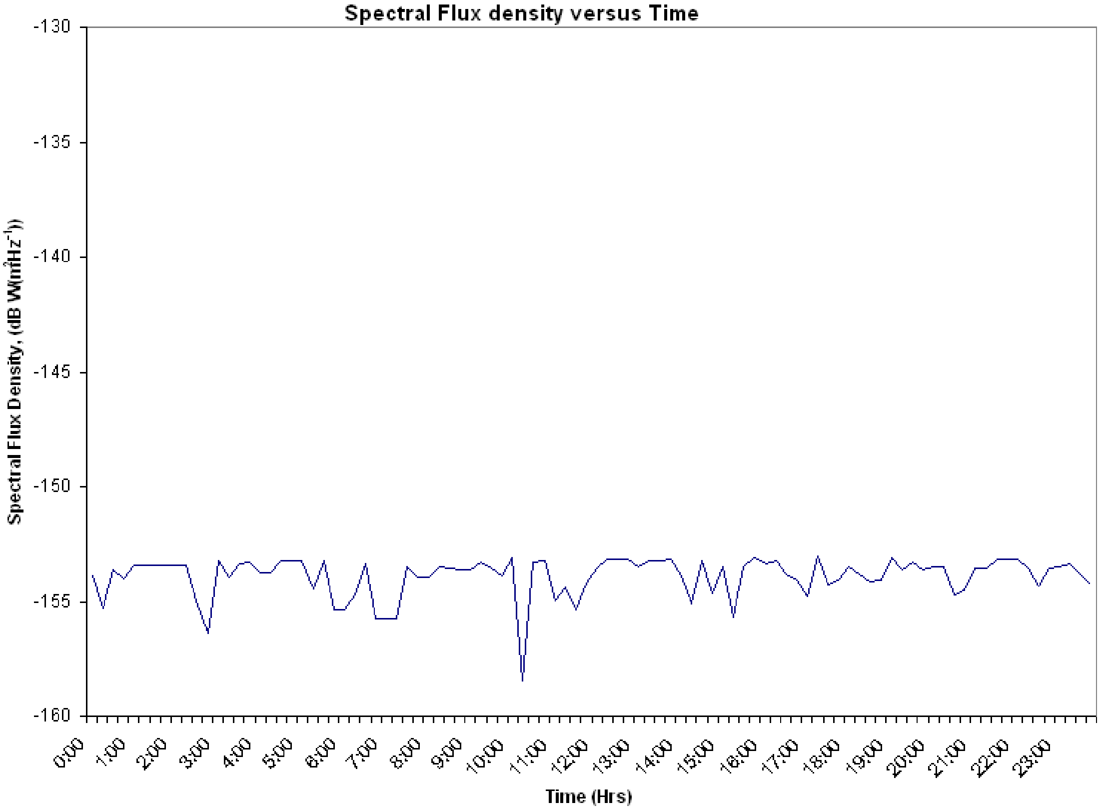


Figure 5.22: The signal fluctuation result at frequency 1420.4 MHz in Sekayu (Potential site)

5.34 The Narrowband's Result Analysis

According to the result, the lowest RFI site at frequency 1419 MHz until 1421 MHz is in Sekayu, Terengganu with average signal -153.93 $dBWm^{-2}Hz^{-1}$ (see Figure 5.21). It is followed by Kg. Bertam in Kelantan (see Figure 5.19) and eventually in Jelebu, Negeri Sembilan (see Figure 5.17). The average signals are -153.94 $dBWm^{-2}Hz^{-1}$ and -153.88 $dBWm^{-2}Hz^{-1}$ respectively. However, the RFI in entire potential sites are low if it is to be compared to the two reference sites. The average signals in the Meteorological station recorded the highest RFI signal in this band with -149.87 $dBWm^{-2}Hz^{-1}$ (Figure 5.15). Meanwhile the average signal at the Physics Department, University of Malaya is *-165.04* $dBWm^{-2}Hz^{-1}$ (see Figure 5.13).

Table 5.2: The narrowband RFI average signals from the entire sites. (Error are obtained from standard deviation of collected data)

	Physics Department	Meteorological Station	Jelebu	Sekayu	Bertam
Average signals (±3.88 $dBWm^{-2}Hz^{-1}$)	-165.04	-149.87	-153.88	-153.93	-153.94

The signal fluctuations at frequency 1420.4 MHz in the potential and reference sites have been analyzed and the investigation has been done for the strength of the RFI signal at daytime and night time. From the results of the analysis, there are no RFI peaks appearing in day and night time at the Physics Department (see Figure 5.14), Jelebu (see Figure 5.18), Bertam (see Figure 5.20) and Sekayu (see Figure 5.22). However, there are four peaks observed at the Meteorological Station, University of Malaya (see Figure 5.16). Three peaks appeared in the day time and one peak appeared in the night time. However we do not know the sources of those intermittent peaks.

For Hydrogen Line analysis at frequency 1420.4 MHz in the potential sites, it was discovered that there are no high man-made RFI sources in the radio astronomy band that has been maintained in MCMC's allocation spectrum. Eventhough the peaks occurred in the frequency band, however the peaks are intermittent. So it is assumed that the signals are very low and cannot disturb our observation.

5.4 Summary of results

Section 5.1 displayed the result of the GIS analysis in Peninsular Malaysia. In section 5.2 a completed map from the overlay of the entire parameters that have been used was depicted in Figure 5.6. This analysis tells us the three potential sites for future radio astronomy observation site in Peninsular Malaysia; they are Sekayu, Bertam and Jelebu. The result from this analysis supports the first objective that has been mentioned in Chapter 1 Section 1.2.

After we recognized potential sites, in February 2009, selected potential site has been setup for RFI observation in two methods, wideband and narrowband. The results for wideband analysis were presented in Table 5.1. The results showed, the lowest RFI site was in Sekayu with average signals -152.32 $dBWm^{-2}Hz^{-1}$. In Sekayu there were three highest peaks that can be concluded as lowest if compared to others.

In narrowband analysis, Sekayu also has been the lowest RFI site in Peninsular Malaysia with average signal -153.93 $dBWm^{-2}Hz^{-1}$. There are no peaks around the Hydrogen line frequency (1420.4 MHz). Finally, in this research it can be concluded that the best site for radio astronomical observation is in Peninsular Malaysia is Sekayu, Terengganu. However, a deeper analysis is still needed.

Chapter 6

Conclusions and Future works

This chapter documents the summary and the conclusion of the research that has been done in order to achieve the objectives.

The first chapter of this dissertation gives an introduction about Radio Astronomy, and it is followed by an overview of the development of the Radio Astronomy field in Malaysia.

Chapter 2 covers the RFI problem that can influence the observation of data from the radio source in space and the application of GIS software for radio astronomy observation in selected sites in Peninsular Malaysia. Furthermore, we listed the RFI sources in Peninsular Malaysia at frequency 1-2000 MHz that is referred as the allocation spectrum from MCMC. This chapter also discusses the GIS software and includes definitions and how GIS can be applied in RFI observation of the selected site. Lastly, in this chapter, we presented the theory of this research. It covers a deeper understanding of RFI, which includes the definition, types and sources. In this chapter, the various subsystems of RFI measuring systems were presented such as the antenna, amplifier and spectrum analyzer.

Chapter 3 discusses the implementation of GIS techniques in Radio Astronomy of the selected site. It covers the study of the research, the methodology of system design, the data collection and information, system design and the development of the database. In this chapter, the parameter selections are presented such as population, population density, road network, transmitter location and land contour data.

Chapter 4 covers the methodology of RFI observation in potential three sites that have been chosen from GIS analysis in Chapter 3. This chapter discusses the procedure of the experiment, the methods, measurement and data processing.

Chapter 5 presents the result from GIS analysis that have been mentioned in Chapter 3 and the result from RFI observations in each potential site that has been mentioned in Chapter 4. From the GIS analysis, we found three potential sites. They are:

1) Sekayu (Latitude: 04^{o}57.967' N, Longitude: 102^{o}57.332' E)
2) Bertam (Latitude: 05^{o}09.991' N, Longitude: 102^{o}02.764' E)
3) Jelebu (Latitude: 03^{o} 03.108' N, Longitude: 102^{o} 03.912' E)

This is followed by the 24 hours RFI observation in every potential site. From the RFI observations result, we found that Sekayu is the best site for future radio astronomical observation in Peninsular Malaysia with average signals in wideband observed to be -152.32 $dBWm^{-2}Hz^{-1}$ (5.86 x 10^{-16} Jy) and in narrowband observed to be -153.93 $dBWm^{-2}Hz^{-1}$ (4.04 × 10^{-16} Jy). The highest RFI signal that we found was in the Meteorological Station (reference site) with average signals in wideband to be -135.13 $dBWm^{-2}Hz^{-1}$ and in narrowband to be -149.87 $dBWm^{-2}Hz^{-1}$.

In my opinion, this research is important to develop the Radio Astronomy field in Malaysia. Furthermore, this thesis can be used as a reference to other RFI surveys because this RFI research is the first research that has been done in Malaysia. Meanwhile the idea to combine the GIS technique to find suitable Radio Astronomy observation selection sites is the first in South East Asia. This works is considered successful. It will benefit the future Radio Astronomy field with the new method and procedures that have been used in this research.

For the future work, we suggest further investigation is needed. RFI observation in 24-hours should be repeated at the potential site to obtain more accurate and efficient data. Meanwhile the GIS parameter should be increased to get a more accurate result. The study area also must be changed from the big scale to the small scale such as from the whole Peninsular Malaysia to each state. A radio quiet and free zone are necessary prerequisites for high quality radio astronomy observations. The understanding and monitoring of the impact of man-made RFI on radio astronomy observations is needed and enables radio astronomers to take adequate action to solve this problem. The action that can be taken is by monitoring the RFI and bringing such data to the attention of authorities and by developing operational RFI measurement at the radio astronomy station.

In conclusion, we concluded our research achieving the objectives. We have performed the GIS analysis to find suitable sites for radio astronomical observation selection sites in Peninsular Malaysia. Then, we have done the 24 hours wide band observations at the frequency 1MHz-2000MHz in the selection potential sites. After that we also have done the 24 hours narrowband observation at frequency 1419MHz-1421 MHz in the selected potential sites. We found out that even at the best site concluded in this work, the 1420.4 MHz frequency is not entirely free from RFI. Eventually, from the research we ensured that the allocation spectrum band that is reserved for radio astronomy activities is protected in Peninsular Malaysia.

Appendix A

List of Publications

All of the data in this thesis have been published in:

A) International Standard index (ISI) journal

1. Zamri Zainal Abidin, Zainol Abidin Ibrahim, Syed Bahari Ramadzan Syed Adnan, Norwati Khairul Anuar (2008). *Investigation of Radio astronomical windows between 1 MHz – 2060 MHz in University Malaya*. New Astronomy, Volume 14, Issue 6, August 2009, pages 579-583.-International Standard index (ISI) journal.

New Astronomy 14 (2009) 579–583

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

Investigation of radio astronomical windows between 1 MHz and 2060 MHz in Universiti Malaya, Malaysia

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ABSTRACT

An indoor and an outdoor radio frequency survey was conducted in Universiti Malaya, Malaysia, as a test site, for the purpose of developing radio astronomy research in Malaysia. This is the first radio astronomical survey of any such done in Malaysia. Observation and analysis were done in the radio frequency spectrum between 1 MHz and 2060 MHz. In this paper, the experimental setup and procedure of surveying are outlined and the measured data are interpreted. The eight radio astronomical windows were investigated from a 24 h observation, with the emphasis on two of the most important radio astronomical windows which are protected by the Malaysian Communications and Multimedia Commission (MCMC). Some intermittent observations were also done for referencing purposes. The radio frequency interferences (RFIs) are found to be relatively low. The overall relative Interference-to-Noise ratio (INR) at this test site ranges between 5.72% and 11.74%. The average strength of RFI in the eight focused radio astronomical windows at this site ranges between −100 dBm and −90 dBm (equivalently between 9.23×10^4 Jy and 93.29×10^4 Jy at resolution bandwidth of 125 kHz).

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2. Zamri Zainal Abidin, Syed Bahari Ramadzan Syed Adnan, Zainol Abidin Ibrahim (2009) *RFI profiles of prime candidate sites for the first radio astronomical telescope in Malaysia*. New Astronomy, Volume 15, Issue 3, March 2010, pages 307-312.- International Standard index (ISI) journal

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New Astronomy

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RFI profiles of prime candidate sites for the first radio astronomical telescope in Malaysia

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A B S T R A C T

Radio astronomy is a very young research field in South East Asia. There has not been a research-grade radio telescope built in this part of the world yet. A plan has been proposed by the University of Malaya's Radio Cosmology Research Laboratory to build a medium-sized radio telescope in order to eventually join the global projects of the Very Long Baseline Interferometry (VLBI) Network and Square Kilometer Array (SKA). Main parameters taken into consideration in finding the main prime candidate sites involves features that produce Radio Frequency Interference (RFI). These features are mainly telecommunication and satellite navigation signals and population density. Other important features considered are rainfall level, land contour and availability for future collaboration with institutions at the chosen sites. In this paper we described the experimental procedure and the RFI measurement on our five prime candidate's sites in Malaysia, covering frequency band from 1 MHz to 2000 MHz. The levels and sources of RFI on these sites were monitored and analyzed. The RFI level in *Langkawi* showed the lowest average −100.33 dBm (4.4×10^6 Jy). These RFI have been found to fluctuate relatively lowly (between 1 dBm and 2 dBm). This site is also ideally located close to the Langkawi National Observatory and we recommend that this site as the best site to build the first research-grade radio telescope in this region.

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B) Proceeding

3. Adnan S.B.R.S , Abidin Z.Z., Anuar N.K. (2008). *RFI profile at frequency 1420.4 MHz for Radio Astronomy in University of Malaya*, University Science of Malaysia Astronomy proceeding, 13-14th August 2008 pp 5-6.

4. Adnan S.B.R.S , Abidin Z.Z., Anuar N.K. (2009). *RFI profile at frequency 1420.4 MHz in University of Malaya*, 3rd International Meeting on Frontiers of Physics (IMPF) proceding, 13-15 January 2009 pp 14-15.

5. Adnan S.B.R.S , Abidin Z.Z.,Rosmadi Fauzi (2009). *The Implementation of GIS in Radio Astronomical observation selection site in Peninsular Malaysia*. 8th International Symposium and Exhibition on Geoinformation proceeding, 10-11 August 2009, pp 23-24.

Appendix B

Allocation spectrum plan from MCMC at frequency 1350 MHz-1452 MHz

SPECTRUM PLAN

1 350MHz to 1 452MHz

Frequency Band (MHz)	ITU Allocation			Malaysian Allocation
	Region 1	Region 2	Region 3	
1350-1400	FIXED MOBILE RADIOLOCATION 5.149 5.338 5.339 5.339A	RADIOLOCATION 5.149 5.334 5.339 5.339A		RADIOLOCATION 5.149 5.339 5.339A MLA45
1400-1427	EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341			EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341 MLA14
1427-1429	SPACE OPERATION (Earth-to-space) FIXED MOBILE except aeronautical mobile 5.341			SPACE OPERATION (Earth-to-space) MLA46 FIXED MOBILE except aeronautical mobile 5.341
1429-1452	FIXED MOBILE except aeronautical mobile 5.339A 5.341 5.342	FIXED MOBILE 5.343 5.339A 5.341		FIXED MLA47 MOBILE 5.339A 5.341

Appendix C

1-The procedures for spatial data entering

1-Click to the add data icon in the ArcGIS software. After that, choose the target spatial data (map) and import to the Arcview (see Figure .C.1).

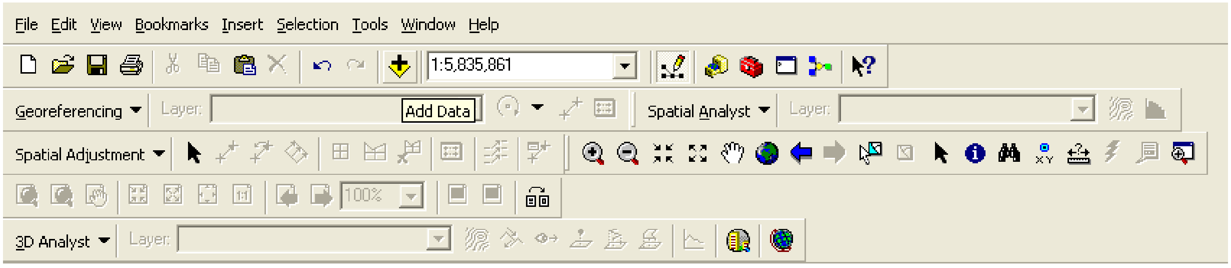


Figure C.1: The add data icon

2- Run the georeferencing procedures to register the map. This procedure is to register the map base to the real coordinates (latitude: longitude). For this technique, we must already have the registered map to register the new map. This technique starts with click the 'add control point' icon. Then click to the registered map and scroll to the new map and click again to the new map at the same point with the registered map. We must choose at least three points to make the georeferencing process (see Figure C.2).

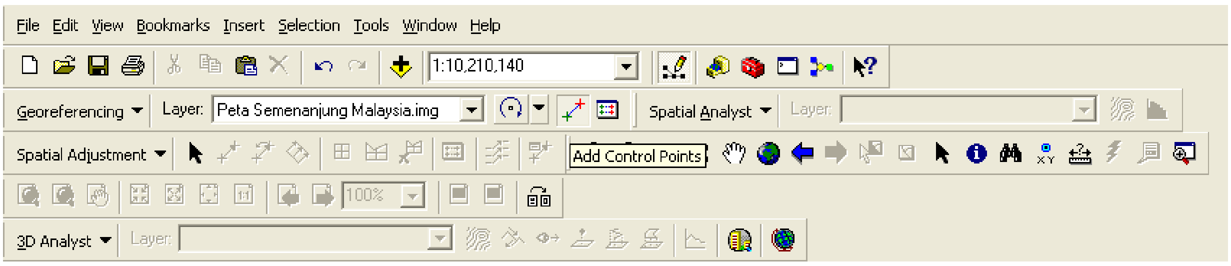


Figure C.2: The add control point icon

After the process is finished click the 'rectify' button (Figure C.3) and click the save button.

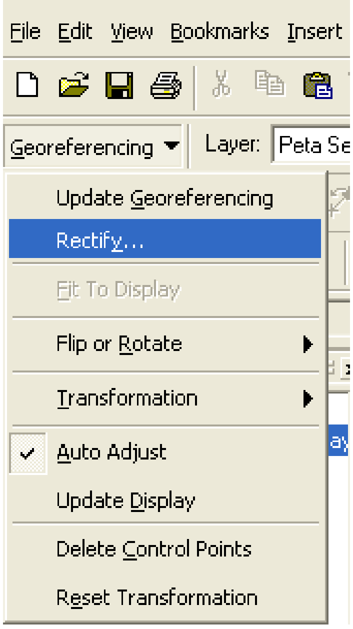


Figure C.3: The rectify icon.

3- After that we must digitize the map that we already registered. To digitize the map we follow the instructions below:

i- Click 'add data' and enter the map. Then open the Arc catalogue and choose 'New Shapefile' (see Figure C.4) by right clicking the mouse.

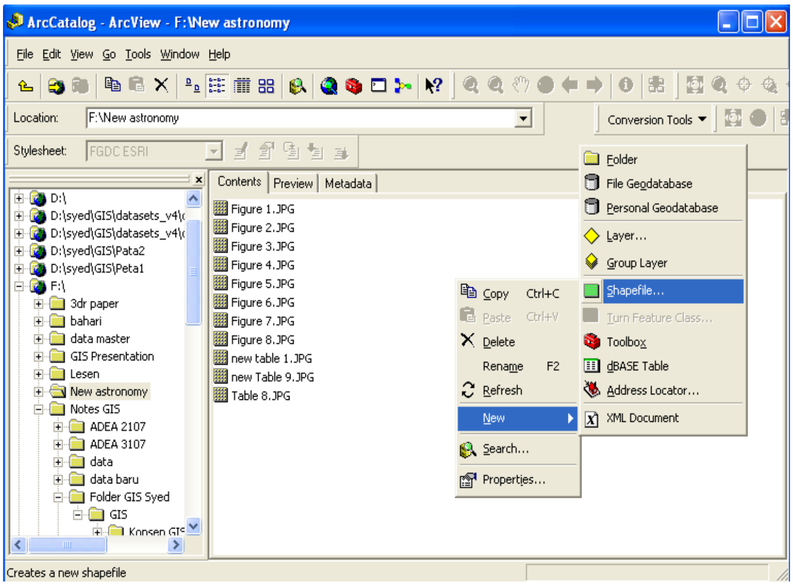


Figure C.4: The shapefile

ii- After that, the selected name and choose 'feature type' as polygon. If you want to digitize the road or river you can choose the 'feature type' as polyline and for state the area you can choose the point. Then click 'ok' (see Figure C.5).

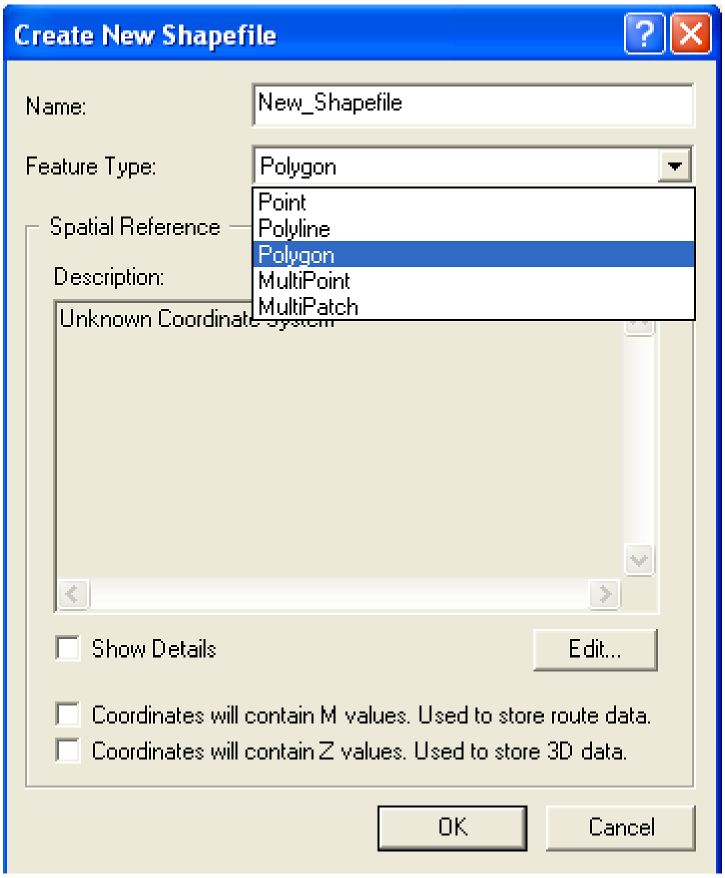


Figure C.5: Create new shapefile

iii- The shapefile must be registered. For this step right click the existing shapefile and choose 'properties' (see Figure C.6). Then click 'select' and choose 'Geography coordinate system' as 'WGS 1984.prj'.

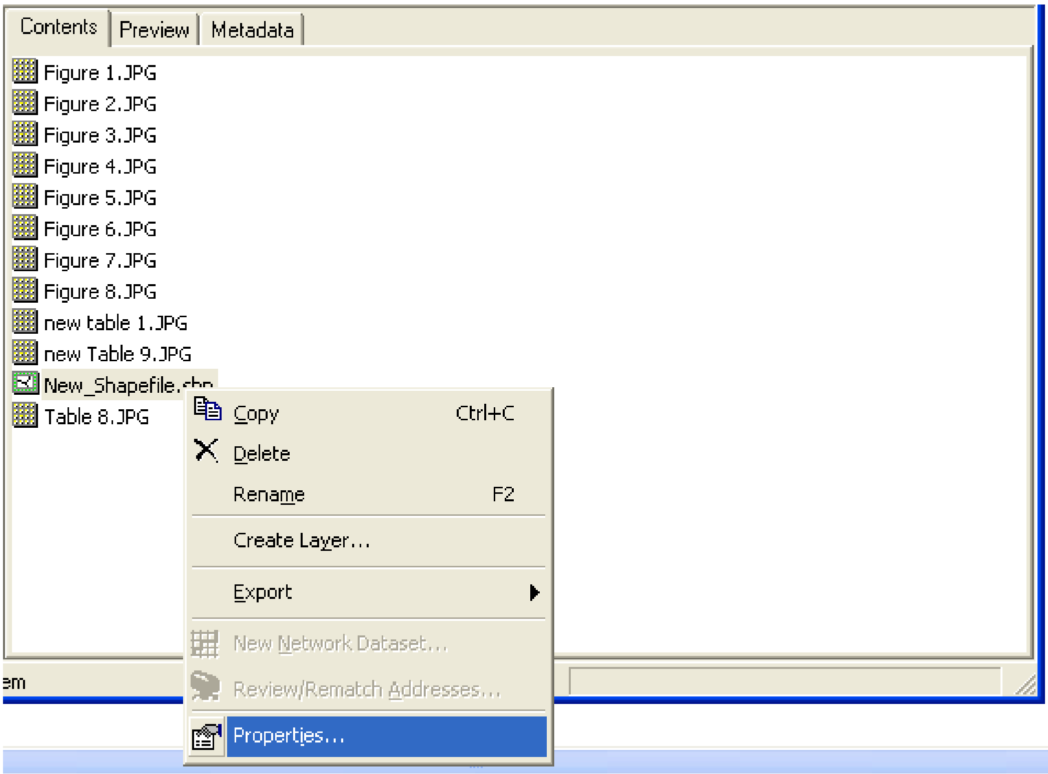


Figure C.6: The properties icon from shapefile

iv- Then click 'Start Editor' as 'Editor' icon (see Figure C.7). Now the digitization process can be started. After the map is digitized click 'Editor' icon again and choose stop editing. Finally the map is saved.

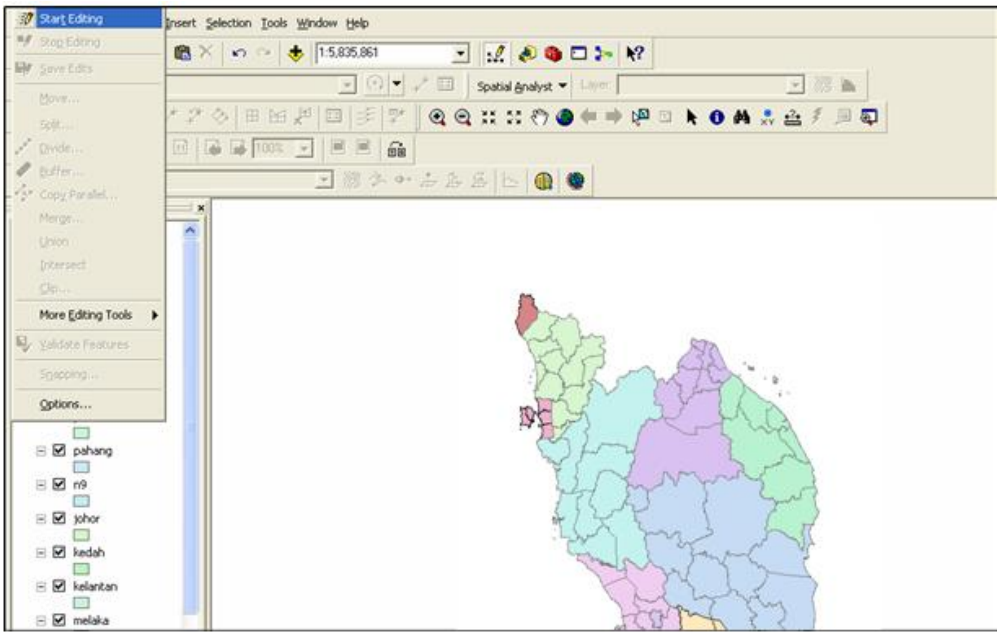


Figure C.7: The start editing icon at editor toolbar

2-Importing attribute data into Arcview

The entering process can be started by right clicking at the 'layer' icon and then choosing 'open attribute table' (see Figure C.8). To start editing choose 'Editor" and click 'Start editing'. The 'add field' is used to add another field in the attribute table. This process can be started with clicking 'Option' in the attribute table and choose 'add field' (see Figure C.9). You can write your own name and choose the 'type' according to the type of data you want to enter (see Figure C.10). When the process is finished click 'stop editing' at the 'Editor' toolbar.

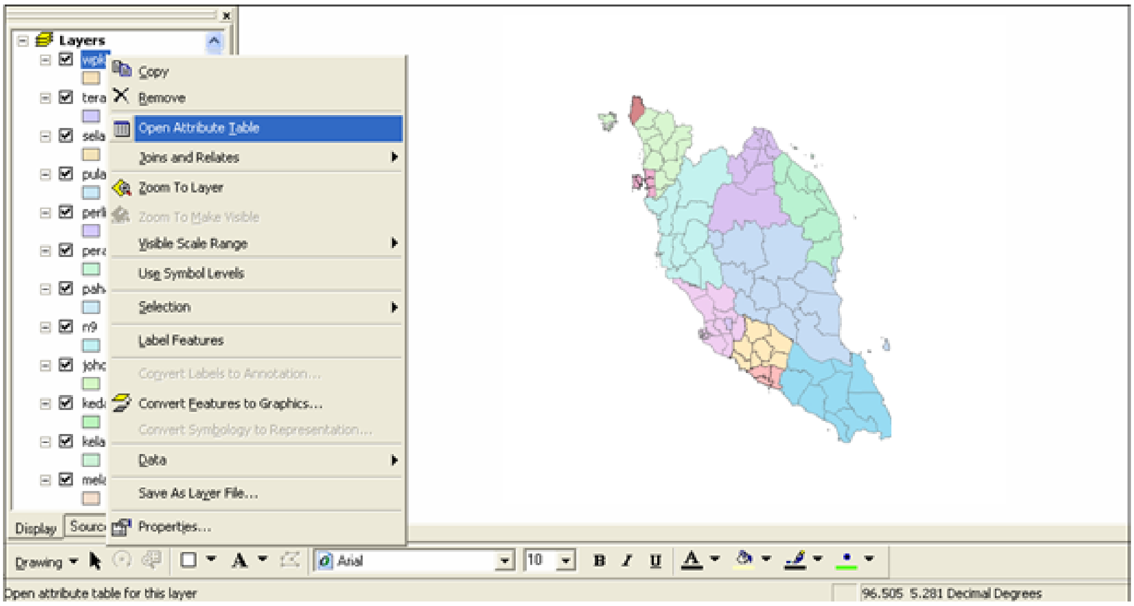


Figure C.8: The open attribute table toolbar

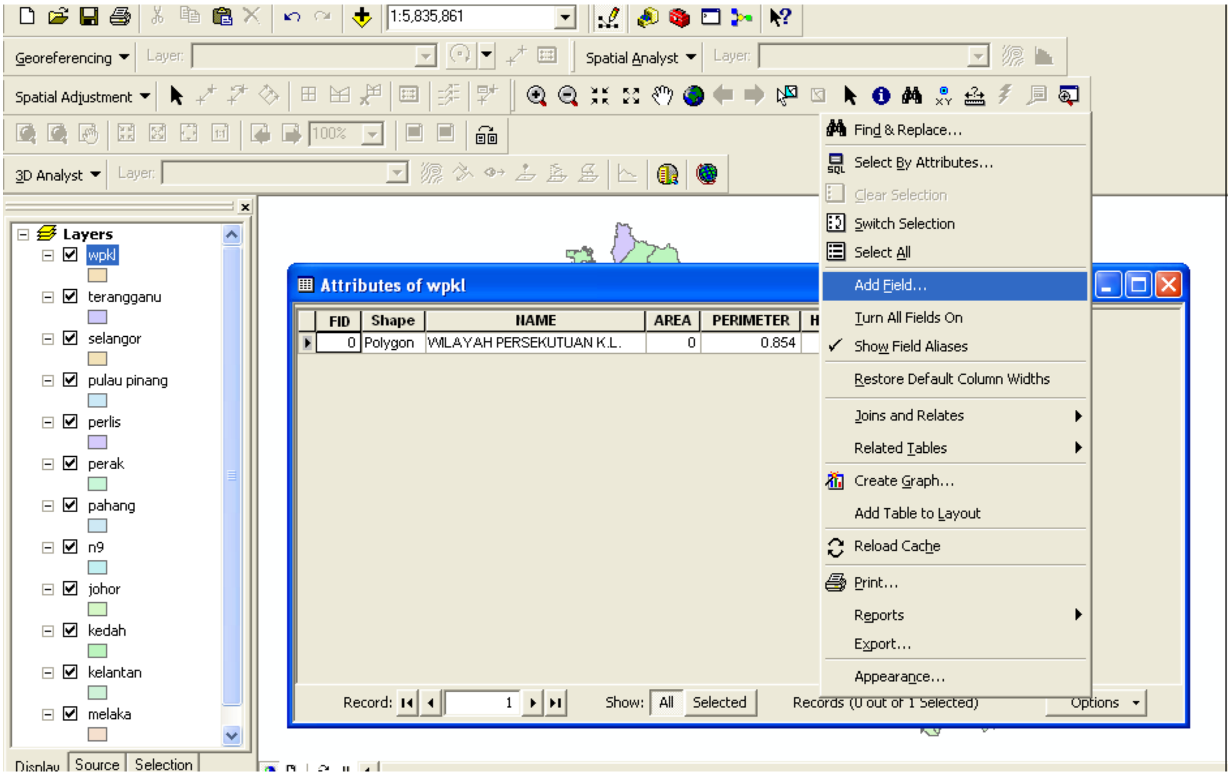


Figure C.9: The add field toolbar

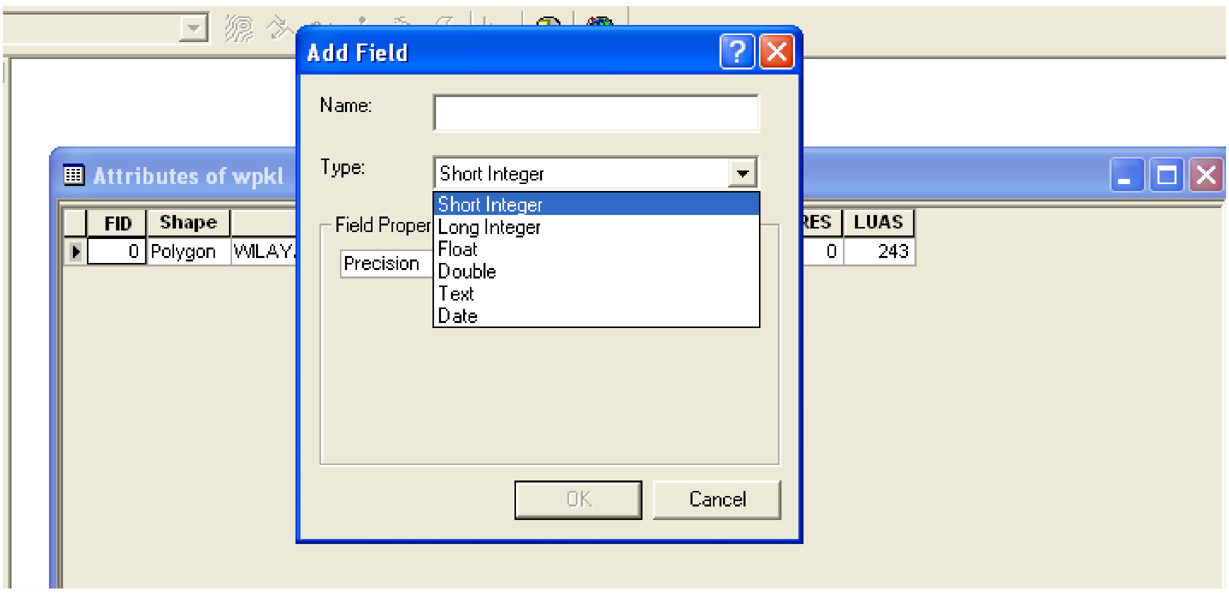
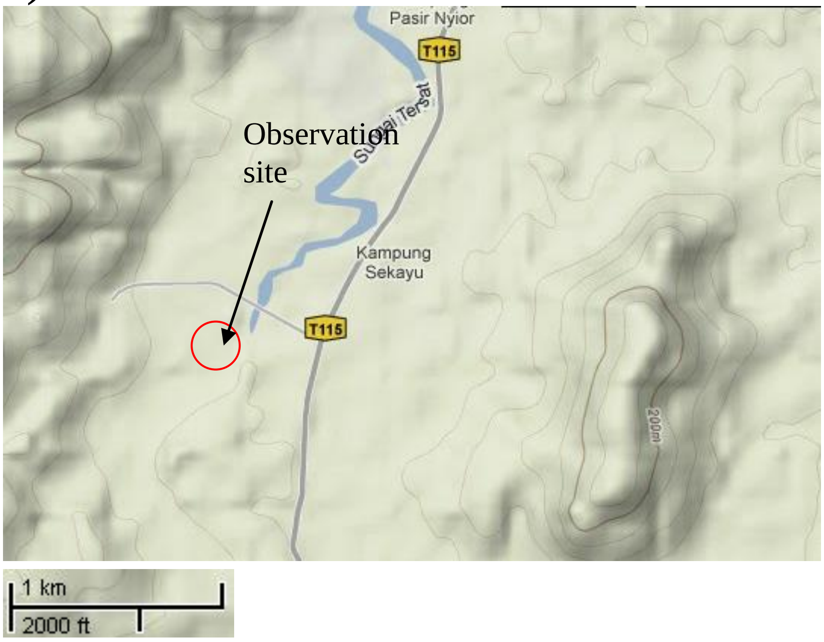


Figure C.10: The open attribute table toolbar

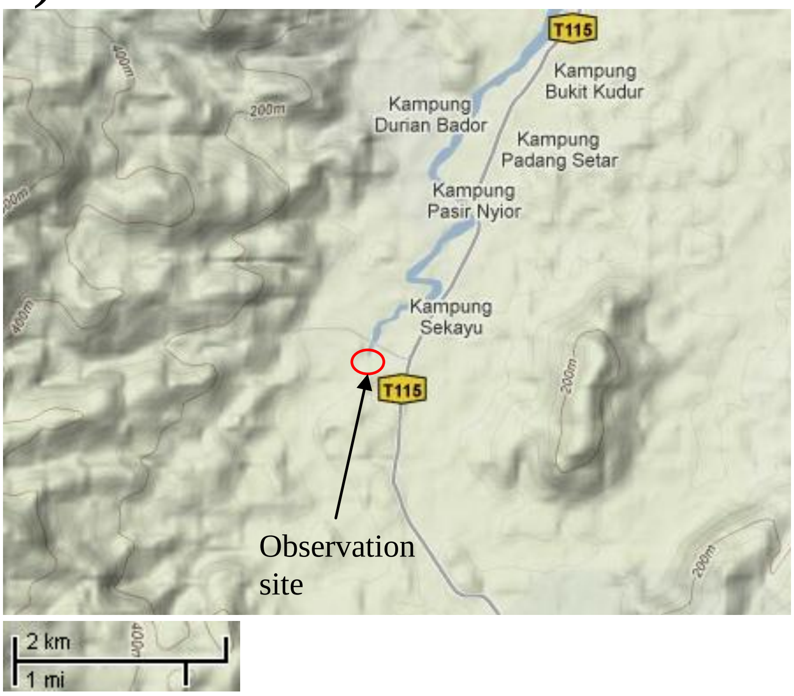
Appendix D

Counter Map of Kampung Sekayu

1)



2)



Appendix E
Lowest Population in each State

(Km squre)	*18987*	*9425*	*15105*	*243*
State	Johor	kedah	Kelantan	Kuala Lumpur
Name of Area	Pulau Babi	Permatang Pasir	Gua Musang	Cheras
population	102	107	135	11,842
Name of Area	P.Pemanggil	Hj.Kudung	Bdr.Kecil Selising	Ulu Kelang
Population	110	1189	141	28,471
Name of Area	P.Aur	Btg Tunggang Kiri	Kala	Ampang
Population	191	1192	153	35,554
Name of Area	Lenggor	Limbong	Bertam	Petaling
Population	298	1128	112	208,322
Name of Area	P.Tinggi	Btg Tunggang Kanan	Tabar	Bandar K.L
Population	270	1645	136	231,458

6657	35965	21005	795	1031
N.Sembilan	Pahang	Perak	Perlis	P.Pinang
Miku	Kelola	Jaya baharu	Sungai Adam	Mukim 15 (Bukit ayer itam)
150	264	340	1,581	52
Parit Tinggi	Pulau Rusa	Belum	Abi	Mukim 5 (Bkt. Balik Pulau)
267	567	120	2,100	165
Langkap	Temai	Belukar Semang	Kurong Batang	Mukim 6(sbrg Perai Selatan)
356	978	1,685	3,115	282
Semerbok	Ganchong	Lambor Kiri	Ngolang	Mukim 16(sbrg Perai Selatan)
498	1,329	1,875	3,145	289
Legong Hulu	Lipat Kajang	Pasir Panjang Ulu	Oran	Mukim 8 (Bkt. Pasir Panjang)
551	1,387	2,943	3,610	839

7979	12955	1652
Selangor	Terengganu	Melaka
Sg.Gumut	Sekayu	Tanjong Tuan
274	164	37
Ulu tinggi	Jengai	Jus
446	1,103	536
Buluh telor	Pulau Perhentian	Tanjong Rimau
555	1,274	625
Peretak	Pasir Raja	Sungei Buloh
1,070	1,440	673
kalumpang	P.Redang	Chohong
2,819	1,453	759

Source:

Department Statistic of Malaysia, 2000

Appendix F

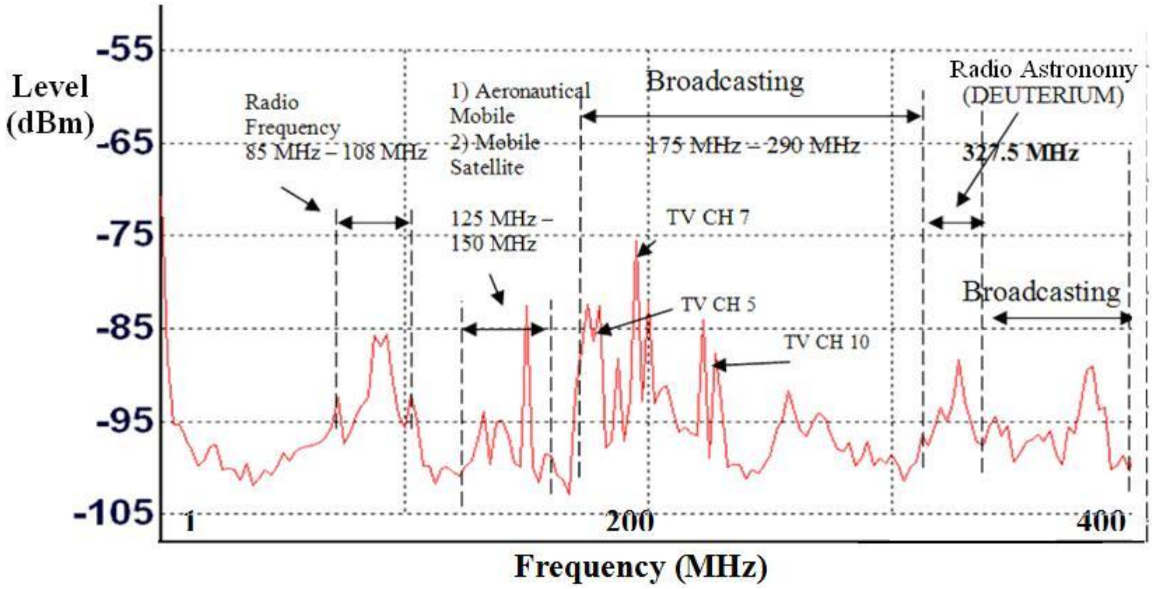
Population Density in Peninsular Malaysia

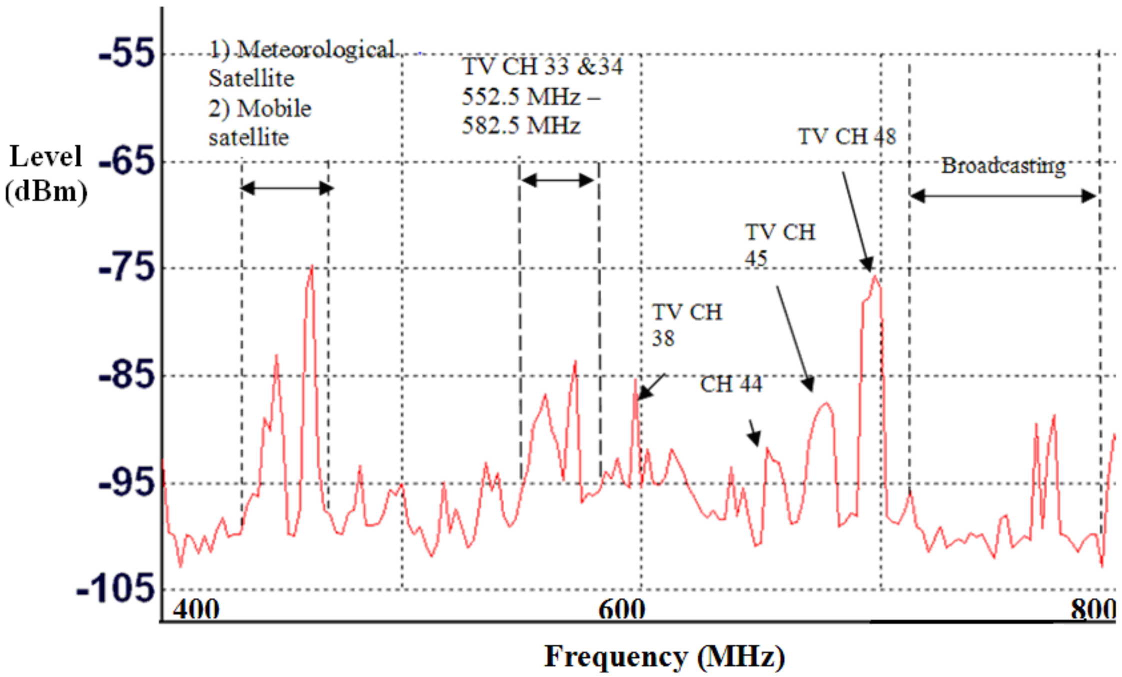
Source:

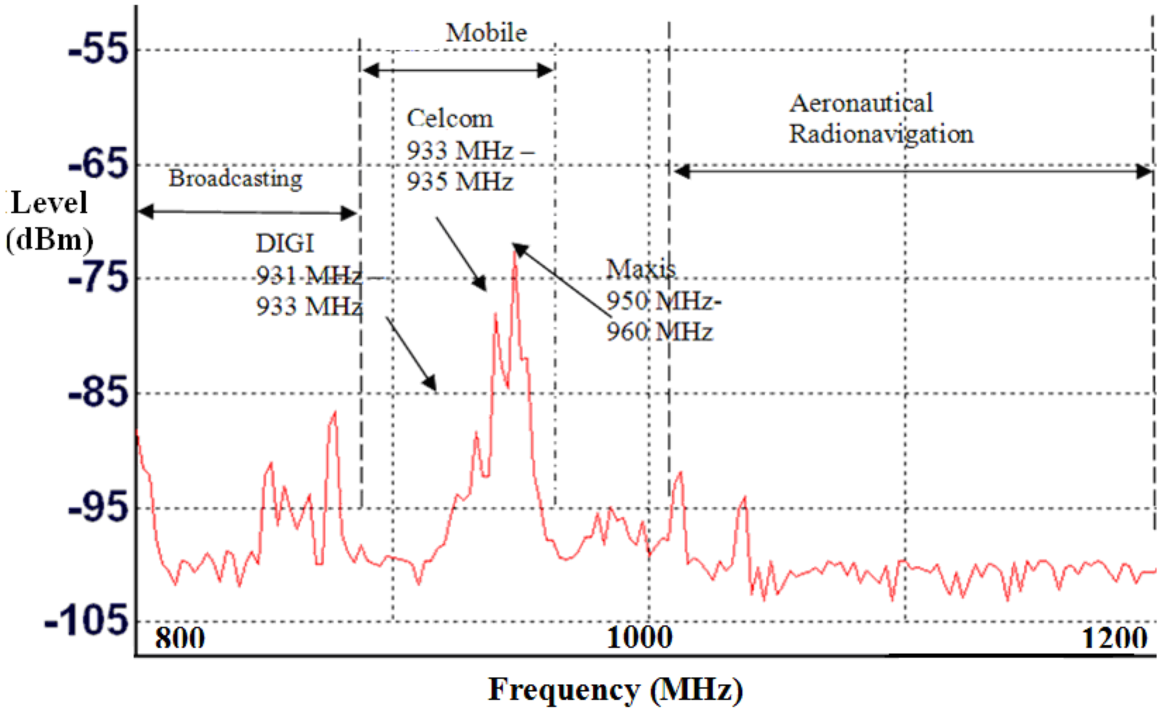
Department Statistic of Malaysia, 2000

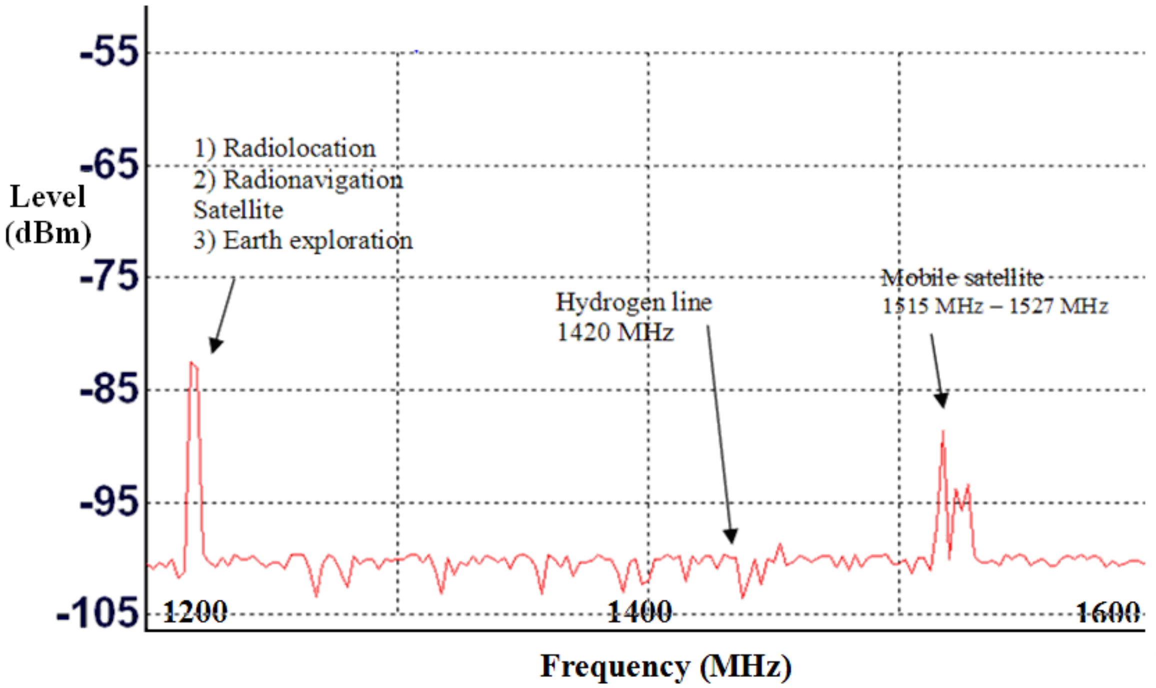
Appendix G

Signal sources at frequency 1 MHz-2000MHz using Omni-directional antenna.






-55
-65
-75
-85
-95
-105
Level
(dBm)
Mobile
Celcom
933 MHz –
935 MHz
Aeronautical
Radionavigation
Broadcasting
DIGI
931 MHz –
933 MHz
Maxis
950 MHz-
960 MHz
800
1000
1200
Frequency (MHz)


-55
-65
-75
-85
-95
-105
Level
(dBm)
1) Radiolocation
2) Radionavigation
Satellite
3) Earth exploration
Hydrogen line
1420 MHz
Mobile satellite
1515 MHz – 1527 MHz
1200
1400
1600
Frequency (MHz)

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